Chapter III

RELATIONSHIP TO POLLUTION OF BOTTOM ORGANISMS

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ECOLOGY OF ANIMAL SAPROBIA

R. Kolkwitz and M. Marsson

In the Reports of the German Botanical Society (22), we published last year the "Ecology of Plant Saprobia" which comprises about 300 species and is intended to facilitate -- as is this paper -- the evaluation of the degree of purity of streams and bodies of water.

In order to characterize the different degrees of self-purification in such waters, we distinguish three main zones and designate these by the following terms (5, 22):

I - Polysaprobiotic Zone;

II - Alpha- and Beta-mesosaprobiotic Zone;

III - Oligosaprobiotic Zone.

If we assume three adequately large and successive ponds of which the first (I) collects putrescible sewage, then the latter will have mesosaprobiotic character after passage into the second pond (II), i.e., it will be in an intermediate stage of mineralization. Upon passage into the third pond (III), the mineralization process of such water would be largely or completely terminated, i.e., the water would have an oligosaprobiotic character (15).

Zone II is asymmetrical since self-purification here takes place rather aggressively in one half of the zone and moderately in the other which explains the subdivision into alpha- and beta-mesosaprobiotic.

Similarly, we can distinguish in rivers or streams receiving putrescible substances (products of protein decomposition and carbohydrates) differing zones as far as the point at which the initial picture is reestablished.

The designation of strong and/or weak mesosaprobiotic in our plant ecological system has here been replaced by alpha- and/or beta-mesosaprobiotic because the words used can give rise to misunderstandings when taken out of context by assuming strong to mean pronounced and weak as little.

As indicated by the terms themselves, the above division into zones presupposes that the action of the chemical factors predominates over that of the physical factors unless the latter control the possibility of existence entirely, e.g. turbulent flow and entrained sand along banks and/or bottom of streams.

Division into the above zones further presupposes that putrescible organic substances exercise a considerable influence on the distribution of the organisms. Proof for the accuracy of this assumption was obtained by us from numerous investigations in many waters of a great number of different regions, especially the North-German Plain. A large part of these observations has not yet been published; however, many chemo-analytical data for this and the close parallels between biological and chemical analysis of water may be found already in our communications published in the Reports of the Institute (Royal Institute for Water Supply and Sewage Disposal). These communications concern ditches and ponds of the trickle fields at Berlin, artificial lakes in the Rhineland, the lower course of the Main River, the Elbe River from Schandau to Hamburg, the Saale River from Halle to its confluence with the Elbe and the Mleczna and Gostine Rivers in Upper Silesia to the confluence with the Vistula. There are also detailed investigations of the Elbe River at and below Hamburg in its relations to the 'outflow from sewers in the extensive work of Volk.

The work of Lauterborn and Marsson indicates that the Rhine has also been examined biologically but the findings of the respective chemical and bacteriological analyses have not yet been published.

The influence of the water-soluble substances on plants is generally more direct than on the animals -- no less important for the self-purification of the waters -- because the former nourish themselves by osmosis and the latter primarily by feeding on the substances. The character of the mud may therefore be of great significance for the distribution of the animals.

The dependence on the composition of the water is especially pronounced for the lower organisms. This explains the dearth in the poly- and alpha-mesosaprobiotic zone of species of higher organisms which have in greater part a less definitely graduated distribution by zone. They are therefore represented predominantly and particularly abundantly in the beta- and oligosaprobiotic zone but may overlap from here into adjacent zones through certain representatives.

An organism reacts as much more strongly to the chemical composition of water as it is more definitely saprophil -- in addition to being saprobiotic -- from the point of view of nutritional physiology which applies e.g. to Antophysa vegetans, Carchesium Lachmanni, vorticella microstoma and others. True saprophil organisms therefore are the principal guide organisms for the chemical composition of the water. The statement (August Püteer, Nutrition of Aquatic Animals, Verworn Journal for General Physiology, Vol. 7, 1907) that appreciable amounts of water-soluble organic substances also serve the nutrition of the animals would appear from the above to be valid in sweet water essentially only for certain lower organisms.

As we have stressed frequently, the main emphasis in the evaluation of the waters should in general not be laid on the individual organisms but on the biocenoses ("Bioconosen") whose particularities cannot here be described in detail. In this respect, we may well apply here the maxim coined by the systematicians according to which one (a single) character is no character. Only in tests of drinking water is it possible for isolated organisms to play an essential role as is frequently shown in the pertinent literature.

The clearest picture of the state of the water will obviously be obtained by a planned consideration of the three typical regions of open water, bank and bottom, especially if we take adequately into account the interaction of the plants and animals in them and the essentially opposite products and requirements of the latter (cf. 17 on methods and instruments for procuring samples).

For an understanding of the relations between the aquatic regions and the saprobiotic zones, we should like to stress here that, for example, a lake deriving oligosaprobiotic character from its plankton and benthos may well contain mesosaprobiotic mud organisms and often does contain them. The same lake may also change its biological picture with the seasons because, e.g., an abundant growth of hydrophyll plants dies off and thus brings mesosaprobiotic elements into the true plankton zone, especially near the banks.

The foundations of the biological evaluation of water find their basis in the proper appreciation of these combinations. Nearly always we must be concerned not only with testing the water but with determining the entire state of a collector.

In the present communication, we have placed the main emphasis on the system and restricted discussion in the text as much as possible. In a more extensive report to be published in the Reports of the Royal Institute for Water Supply and Sewage Disposal, we intend to combine the ecological systems of both plants and animal organisms.

The following brief considerations are intended to serve as a characterization in biological and chemical respect of the principal zones referred to initially.

I - The zone of polysaprobia is characterized chemically by a certain degree of wealth of high-molecular, putrescible and organic substances (protein components and carbohydrates) which enter the collectors in the directly putrescible sewage from cities and agricultural, industrial and other enterprises. A decrease of oxygen content of the water accompanied by reduction manifestations, formation of hydrogen sulphide in the mud and an increase of carbon dioxide often are the chemical sequels of this.

Organisms generally occur in great numbers but with a certain monotony; especially Schizomycetes and (usually bacteriophage) colorless flagellates are frequent. The bacteria developed in standard nutrient gelatine may exceed 1 million per ccm water. Organisms with high oxygen requirements obviously are generally completely absent. Fishes usually avoid remaining in this zone for any length of time.

Plant organisms preferring hydrogen sulphide in this zone may recur in H_2S sources in the oligosaprobiotic zone.

II - The zone of the mesosaprobia is divided into a alpha- and/or beta-saprobiotic section. It generally succeeds the polysaprobiotic zone. In the alpha-section which adjoins the former, self-purification takes place still rather agressively as already mentioned but with the simultaneous occurrence of oxidation manifestations -- in contrast to zone I -- which are conditioned in part by the oxygen production from chlorophyllous plants.

The protein components contained in the water are probably already decomposed down to asparagin, leucine, glycocoll, etc., which results in a qualitative difference from zone I.

In the beta-section, the decomposition products already approach mineralization. Normal, generally nitrate-containing effluents from the trickle fields are most properly included in this zone.

All organisms of the mesosaprobiotic zone usually are resistant to minor action by sewage and its decomposition products. Notable is among other factors the content of the zone of Diatomaceae, Schizophyceae and many Chlorophyceae and some higher plant organisms. Higher and lower animal organisms are also found in a great number of individuals and varieties.

III - The zone of the oligosaprobia is the domain of (practically) pure water. If it was preceded by a self-purification process locally or chronologically, it succeeds the mesosaprobiotic zone and then represents the termination of mineralization. However, we here include also lakes in which the water does not undergo a mineralization process properly speaking. The oxygen content of the water may often remain permanently close to the saturation limit and occasionally even exceed the latter (as a function of the air dissolved in the water). The content of organic nitrogen usually does not exceed 1 mg/lit. The water is generally transparent to a considerable depth, except at times of abundant plant growth. The number of bacteria developed on standard nutrient gelatine is generally low. In contrast to the polysaprobiotic zone, it amounts to only a few hundreds and infrequently thousands of bacteria per ccm water.

Both the plant and animal plankton of our clean country lakes belongs in this zone. We already pointed out that the mud of such waters may have a beta-mesosaprobiotic character.

Further characteristics of the three principal zones will be found in "Ecology of Plant Saprobia".

Catharobia, i.e., inhabitants of perfectly pure water, have here not been listed intentionally because they have nothing or almost nothing to do with the self-purification of any of these waters. We might count inhabitants of pure mountain streams among them (e.g. Planaria alpina Dana) but the aeration and coolness of the water plays a greater role for them on the basis of our present experience than the particular pure quality of the water.

We are probably justified in already pointing out here that the greater part of the animal organisms living in these waters can advance further into contaminated zones than we have been inclined to assume so far, provided they find the required amount of oxygen.

Ecological System of Animal Saprobia

Within the three principal ecological groups, the organisms listed here and which number more than 500, are arranged in accordance with the natural system, except for the fishes. As for the plant saprobia, we have here also based ourselves in the classification of the various animals on our own observations in the open as far as possible. We endeavored to find the centers of optimum growth and development of the organisms especially at locations with graduated self-purification and determined the position in the ecological system on the basis of these observations.

We do not want to fail to point out here that many pertinent data in literature are incomplete. This is due to the fact that until the present time too few different locations had been investigated and that there usually did not exist any chemical analysis which is highly desirable for these purposes. Occasionally an observer unfamiliar with local conditions has great difficulty in arriving at an accurate evaluation of the character of the particular body of water.

Since it was obviously impossible to enumerate all organisms occurring in water and suitable for the present purposes, we have selected those -- by avoiding any overloading with names of the system here as also in the case of the plants -- which are of definite interest for the evaluation of the state and the self-purification of water on the basis of the present investigations. We need not specifically point out that further investigations may result in future additions to the listing.

In spite of this, the present system already forms a relatively complete whole because we have listed sufficient organisms for each zone so that they already afford a thorough characterization.

In looking over the system, it will be noted that the names of Linné and Ehrenberg occur frequently which is a sign that we have utilized for evaluation as far as possible the more frequent and generally known organisms.

We have endeavored to furnish the most complete enumeration of poly- and alpha-mesosaprobiotic organisms because these are the most important (as inhabitants of the locations of intensive self-purification) for the evaluation of the water.

In order to prevent any too severe evaluations of the degree of purity of the water, we have restricted -- while trying to maintain completeness as far as possible -- the groups of the organisms just named as far as possible and have instead pointed out any possible overlapping of the purer zones into the preceding zones.

The colorless flagellates have been taken into account fully in accordance with their frequency and extensive distribution. They are particularly characteristic for the poly- and alpha-mesosaprobiotic zones.

The Chrysomonodales, Cryptomonodales, Euglenales, Peridiniales and (partly) Protococcales, all part of the flagellates, have already been treated in the plant ecology, not because we meant to stress their belonging to the vegetable kingdom but because all oxygen-producing (aerating) organisms should be grouped in one system as far as possible.

The Ciliata have the greatest significance in the evaluation of the degree of contamination of many water courses and especially their contaminating affluents which daily observation has confirmed for us over many years. They have therefore been taken into account particularly, the more so since they can be determined more easily than the small flagellates. Spongiae are in general not very suitable for evaluation of water on the basis of our present investigations although they may be often considerably advanced in their development through nutrient affluents.

Among the Vermes, the limicolus tubificids are of considerable importance for the evaluation of the poly- and alpha-mesosaprobiotic zone whereas others belong more to the zone of pure water. The nematodes, occupying the intermediary position in comparison with them, are important for microscopic analysis. The greater part of the species is of lesser importance for water evaluation on the basis of the present investigations but may play an important role in the consumption and loosening up of mud.

We gathered extensive data on the Rotatoria so that we were able to utilize them sufficiently thoroughly especially in the evaluation of streams in addition to other animal and plant groups.

Although the Bryozoa are widely distributed, they have so far been investigated very little in respect to their suitability for water evaluation.

The greater part of the molluscs have been classified in the group of oligosaprobiotic organisms. This indicates that -- similar to the higher aquatic plants -- most of them are not used very much for the differentiation of the different zones of importance in the characterization of self-purification. However, they are of the greatest importance for the evaluation of the state of water merely by their role as indicators. They may indicate toxic agents by their sudden decay, asphyxiation from lack of oxygen through putrefaction, lack of calcium through their almost complete absence, etc.

Molluscs may also play an important role as scavengers of detritus -- as do the snails as omnivora and vegetarians -- in keeping streams and other bodies of water clean.

As far as possible, Crustaceae have been considered for water investigations by us and utilized in the ecological system. However, they would seem to merit -- especially the Cyclopida -- further study in regard to the interrelation between distribution and water character.

Arachnoidea need be considered for general biological analysis only to a minor degree on the basis of our present investigations. Insect larvae and, in part, the adult insects -- with the exception of the red larvae of Chironomus and others -- play a role in the evaluation of waters only insofar as they do not advance into contaminated zones. When they occur abundantly, as is often the case, their activity in feeding and the many adult insects in their escape from the water have great importance for keeping the latter clean and may also be of considerable value as fish feed by reason of their relative size.

The various species of insect larvae could be taken into consideration only very little in the present state of science because determination of type from the larvae is usually not possible. It becomes necessary to breed the imagoes which has not yet been done on a planned basis for the present purpose either by us or anyone else to judge from the available literature.

At a summary review, most Pisces can be classified under two groups different by nature: the mud fishes often living in purposely fertilized ponds, and the predatory fish. On this basis and in consideration of other particularities of habitat, we have placed part of the fishes in the beta-mesosaprobiotic and the others in the oligosaprobiotic zone. Many fishes, in particular those with greater vital tenacity, also enter the alpha-mesosaprobiotic zone in feeding and come close to the polysaprobiotic zone but seem to prefer the purer zones wherever possible. This would seem to be valid also for their spawn.

Among the Aves, the gulls (especially Larus ridibundus L), crows (especially Corvus cornix L) and ducks (usually Anas boschas L) are noteworthy as scavengers of lumps of sewage and proliferating sewage fungi.

I. Polysaprobia

Rhizopoda

Hyalodiscus limax (Duj.)
" guttula (Duj.)
} both often together with Polytoma and Spirillae; when isolated, also mesosaprobiotic.

Flagellata

Cercobodo longicauda (Duj.) Senn.
=Cercomonas longicauda Duj.
=Dimorpha longicauda (Duj.) Klebs.
=Dimastigamoeba longicauda Klebs., overlaps into alpha-mesosaprobiotic zone.

Oicomonas mutabilis Kent.
Bodo putrinus (Stokes) Lemm.
Trepomonas rotans Klebs.
Hexamitus inflatus Duj.
} tends also to be alpha-mesosaprobiotic.
" crassus Klebs.
" pusillus Klebs.
" fissus Klebs.
" fusiformis Klebs.
} overlaps into alpha-mesosaprobiotic zone.

Ciliata

Paramaecium putrinum Cl. & L.
Vorticella microstoma Ehrbg.
" putrina O.F. Müller

Vermes

Tubifex tubifex (O.F. Müller), when predominant and abundant.

Diptera

Eristalis tenax L., larvae, often in highly contaminated trickle-filled ditches and strongly hydrogen-sulphide-containing storage areas; also in the mesosaprobiotic zone.

II. Mesosaprobia

1. Alpha-mesosaprobiotic

Rhizopoda

Trinema enchelys (Ehrbg.) Leidy.
Diplophrys archeri Barker.
Pamphagus hyalinus Leidy.
" armatus Lauterb.
Cryptodifflugia oviformis Penard.

Flagellata

Ciliophrys infusionum Cienk; frequent inhabitant of contaminated aquaria.
Cercobodo radiatus (Klebs.) Lemn.
=Dimorpha radiata Klebs.
Cercomonas clavata Perty.
" crassicauda Duj.
Oicomona termo (Ehrbg.) Kent.
Monas vivipara Ehrbg.
" vulgaris (Cienk.) Senn.=Monas guttula Ehrbg.
" arhabdomonas (Fisch) H. Meyer.
Anthophysa vegetans (O.F. Müll.) Bütschli., very typical for alpha mesosaprobiotic zone; when colonies die off in pure water, the stems remain.
Amphimonas globosa, Kent
" fusiformis Mez.
Bodo globosus Stein.
" mutabilis Klebs.
" minimus Klebs.
" caudatus (Duj.) Stein.
" saltans Ehrbg., also in the polysaprobiotic zone.
" ovatus (Duj.) Stein
Spongomonas intestinum (Cienk.) Kent, also in the beta-mesosaprobiotic zone.
Dallingeria drysdali Kent, also in the beta-mesosaprobiotic zone.
Pleuromonas jaculans Perty.

Phyllomitus amylophagus Klebs.
Rhynchomonas nasuta (Stokes) Klebs.
Tetramitus descissus Perty
" salcatus Klebs.
" pyriformis Klebs.
" rostratus Perty.
Urophagus rostratus (St.) Klebs.
Trigonomonas compressa Klebs.
Trepomonas agilis Duj., also in the beta-mesosaprobiotic zone.
" steini Klebs.
Menoidium pellucidum Perty.
Astasiopsis distorta (Duj.)
Astasia margaritifera Schmarda = Astasiodes.
Euglenopsis vorax Klebs.
Peranema trichophorum (Ehrbg.) St.
Heteronema tremulum Zach.
" (=Zygoselmis) acus (Ehrbg.) St.
Scytomonas pusilla Stein.
Chilomonas paramaecium Ehrbg., also in the beta-mesosaprobiotic zone.
Spirochaete plicatilis Ehrbg.

Ciliata

Urotricha farcta (Ehrbg.) Cl. & L.
Amphileptus claparedi Stein, possibly also polysaprobiotic.
" carchesii Stein.
Lionotus varsaviensis Wrz.
Loxophyllum meleagris (O.F. Müll.) Duj., also in the beta-mesosaprobiotic zone.
Cyclogramma rubens Perty
(=Nassula Clap. & L. & A.)
Chilodon uncinatus Ehrbg., also in the beta-mesosaprobiotic zone.
Trochilia palustris Stein, also in the beta-mesosaprobiotic zone.
Leucophrydium putrinum Roux.
Glaucoma scintillans Ehrbg., also in the beta-mesosaprobiotic zone.
Colpidium colpoda Stein.
Colpoda cucullus Ehrbg.
" parvifrons Cl. & L.
" steini Maupas
} also in the beta-mesosaprobiotic zone.
Loxocephalus granulosus Kent.
Paramaecium caudatum Ehrbg.
Cyclidium glaucoma Ehrbg.
Spirostomum ambiguum Ehrbg., also in the beta-mesosaprobiotic zone.
Stentor coeruleus Ehrbg.
" roeseli Ehrbg., also in the beta-mesosaprobiotic zone.
Gyrocoris oxyura Stein
=Caenomorpha medusula Perty, was also found abundantly in stagnant hydrogen sulphide-containing river water in which oxygen could not be demonstrated with the Winkler method.
Urostyla weissei St. = U. multipes (Cl. & L.)., possibly also polysaprobiotic.
Gastrostyla mystacea (St.)
Oxytricha fallax Stein.
" pellionella Ehrbg.
Stylonychia mytilus Ehrbg., also in the beta-mesosaprobiotic zone.
Gerda glans Lachm.
Vorticella convallaria Ehrbg.
Carchesium lachmanni Kent.
Epistylis coarctata, Cl. & L.
" plicatilis Ehrbg., also in the beta-mesosaprobiotic zone.

Suctoria

Podophrya carchesii Cl. & Lachm.
" fixa Ehrbg., also in the beta-mesosaprobiotic zone.

Vermes

Enchytraeus humicultor Vejd.
Pachydrilus pagenstecheri (Ratz.) Vejd.
Lumbriculus variegatus (Müll.) also in the beta-mesosaprobiotic zone.
Limnodrilus udekemianus Clap.
" hoffmeisteri Clap.
Tubifex tubifex (Müll.), overlaps into the polysaprobiotic zone (cf. the latter) and beta-mesoprobiotic zone.
Lumbricillus lineatus (Müll.), advances from the sea to contaminated brackish and/or sweet water.
Psammoryctes barbatus Vejd.
Dero limosa Leidy.
Aeolosoma quaternarium Ehrbg.
Lumbricus rubellus Hoffm.
Monohystera macrura De Man, also in the beta-mesosaprobiotic zone.
Tripyla setifera Butschli
Trilobus gracilis Bast.
Plectus tenuis Bast.
Diplogaster rivalis (Leyd.).

Rotatoria

Rotifer vulgaris Schrank, also in the beta-mesosaprobiotic zone.
" actinurus Ehrbg., occasionally polysaprobiotic; occurs in water enriched with hydrogen sulphide and poor in oxygen as demonstrated by the Winkler method.
Callidina elegans Ehrbg., and other varieties.
Triarthra longiseta Ehrbg., often abundant in contaminated village ponds and collectors which receive sewer outflow.
cf. var limnetica.
Hydatina senta Ehrbg., occurs isolated also in the weak mesosaprobiotic zone.
Diglena biraphis Gosse
" caudata Ehrbg.
} also in the beta-mesosaprobiotic zone.
Diplax compressa Gosse.
" trigona Gosse.
Diplois daviesae Gosse.
Colurus bicuspidatus Ehrbg; isolated, also in the beta-mesosaprobiotic zone.
Brachionus angularis Gosse, also in the beta-mesosaprobiotic zone.
" militaris Ehrbg., also in the beta-mesosaprobiotic zone.

Mollusca

Sphaerium (=Cyclas) corneum L., occurs abundantly in the Spree River downstream from the Berlin emergency outlets; very resistant to organic sewage; also in beta-mesosaprobiotic mud.

Crustacea

Asellus aquaticus (L.) Ol., when in large amounts and well developed; often between putrefying Spherotilus on which it may feed.

Neuroptera

Sialis lutaria L., larvae, very resistant, often in very much dirt; also in mud of Lake Lucerne and elsewhere.

Hemiptera

Velia currens Febr. Very resistant against contamination.

Diptera

Chironomus plumosus L., larvae, abundant occurrence very typical for this region; also in the poly- and beta-mesosaprobiotic zone. This species with its red larvae is a collective species.
" motitator (L.), also in the beta-mesosaprobiotic zone.
Tanypus monilis (L.), also in the beta-mesosaprobiotic zone.
Caenia fumosa Stenh., larvae, imago along the edges of purine ditches.
Ptychoptera contaminata L., larvae; often associated with Beggiatoa and Euglena virdis.
Psychoda phalaenoides (L.), larvae
" sexpunctata Curtis.
" =Ps. phalaenoides Meigen, larvae.
Stratiomys chamaeleon L., larvae.

2. Beta-mesosaprobiotic

Rhizopoda

Amoeba brachiata Duj.
" verrucosa Ehrbg.
" radiosa Ehrbg. =Dactylosphaerium.
Pelomyxa palustris Greff, also alpha-mesosaprobiotic.
Cochliopodium bilimbosum Leidy.
" pellucidum (Arch.) Hertw. & Less., also alpha-mesosaprobiotic.
Arcella vulgaris Ehrbg., also alpha-mesosaprobiotic.
Centrophyxis aculeata (Ehrbg.) St.
Euglypha alveolata Duj.
Platoum stercoreum (Cienk.)
Pamphagus mutabilis Bailey.

Heliozoa

Actinophrys sol Ehrbg., also alpha-mesosaprobiotic.
Actinosphaerium eichhorni (Ehrbg.) also alpha-mesosaprobiotic.
Spaerastrum fockei (Arch.).
Clathrulina elegans Cienk., also alpha-mesosaprobiotic.

Flagellata

Mastigamoeba aspera F.E. Sch.
" invertens Klebs.
" limax Moroff.
" polyvacuolata Moroff.
Eucomonas socialis Moroff.
Spaeroeca volvox Lauterborn.
Bodo celer Klebs.
" rostratus (Kent) Klebs.
" uncinatus (Kent) Klebs.
" repens Klebs.
Pleuromonas jaculans Perty.
Menoidium falcatum Zach.
Phialonema cyclostomum St.=Urceolus cyclostomus (St.) Mereschk.
Anisonema acinus Duj.
Entosiphon sulcatum (Duj.) St.
Chilomonas paramaecium Ehrbg.; also alpha-mesosaprobiotic.

Ciliata

Urotricha lagenula (Ehrbg.).
Enchelys pupa Ehrbg.
" silesiaca Mez.
Prorodon farctus (Cl. & L.).
" platyodon Blochm.
Lagynus elegans (Engelm.) tends to be also oligosaprobiotic.
Coleps hirtus Ehrbg., also alpha-mesosaprobiotic.
Didinium nasutum Stein.
Disematostoma buetschlii Lauterb.
Loxophyllum armatum Cl. & L.
" (= Lionotus) fasciola Cl. & L.; also alpha-mesosaprobiotic.
" lamella Cl. & L.
Trachelophyllum lamella (L. F. M.).
" pusillum Clap.
Trachelius ovuum Ehrbg.
Loxodes rostrum Ehrbg.
Nassula elegans Ehrbg.
" ornata Ehrbg.
Chilodon cucullulus Ehrbg., also alpha-mesosaprobiotic.
Opisthodon niemeccensis Stein.
Dysteropsis minuta Roux.
Frontonia acuminata (Ehrbg.) Cl. & L.
Chasmatostoma-reniforme Engelm.
Uronema griseolum (Mps.).
" marinum Duj.
Cinetochilum margaritaceum Perty.
Paramaecium bursaria (Ehrbg.) Focke.
" aurelia (O.F. Müll.) also alpha-mesosaprobiotic.
Urocentrum turbo Ehrbg.
Lembadion bullinum (O.F. Müll.) Perty.
Pleuronema chrysalis (Ehrbg.) Stein.
Balantiophorus minutus Schew., tends to be also oligosaprobiotic.
Blepharisma lateritium (Ehrbg.) Stein.
Metopus sigmoides (O.F.M.) Cl. & L., also alpha-mesosaprobiotic.

" contortus Levander.
" pyriformis Levander.
Plagiopyla nasuta Stein.
Spirostomum teres Cl. & L.
Condylostoma vorticella Ehrbg., tends to be also oligosaprobiotic.
Bursaria truncatella O.F. Müll.
Tylacidium truncatum Schew.
Climacostomum virens Stein.
Stentor polymorphus Ehrbg., tends to be also oligosaprobiotic.
" igneus Ehrbg.
" niger Ehrbg.
Halteria grandinella (O. F. Müll.).
Tintinnidium fluviatile (St.); tends to be also oligosaprobiotic.
Uroleptus musculus Ehrbg.
" piscis (Ehrbg.)
Stylonychia mytilus Ehrbg.
Euplotes patella Ehrbg.
" charon Ehrbg.
Aspidisca costata Stein
" lynceus Ehrbg.
} also alpha-mesosaprobiotic.
Astylozoon fallax Engelm.
Vorticella campanula Ehrbg.
" patellina Ehrbg.
" citrina Ehrbg.
Carchesium epistylis Cl.
Zoothamnium arbuscula Ehrbg.
Epistylis umbellaria Lachm. and other species.
Cothurnia crystallina Ehrbg.

Suctoria

Sphaerophrya pusilla Cl. & L. and other species which are in part not yet accurately determined.
Podophrya quadripartita Cl. & L.
Acineta grandis Kent.

Spongiae

Ephydatia muelleri (Lieberkuhn)
" fluviatilis (L.)
Euspongilla lacustris (L.)
Spongilla fragilis Leidy
} also overlap into adjacent zones; very little suitable for water evaluation as far as is known now.

Hydroidea

Hydrae on Lemnae occasionally also in this region; cf. oligosaprobiotic zone.

Vermes

Rhynchelmis limosella Hoffm.; isolated; also alpha-mesosaprobiotic.
Eiseniella tetraedra (Sav.). amphibian
Criodrilus lacuum Hoffm.
Nephelis vulgaris Moq.-Tand, overlaps
Clepsine bioculata (Bergm.)
" sexoculata (Bergm.)
} tends to be also oligosaprobiotic.
Naïs elinguis Müll., also alpha-mesosaprobiotic.
Stylaria lacustris (L.)
Haemopis sanguisuga (Bergm.) = Aulostomum gulo Moq.-Tand.
Polycelis nigra (Müll.) Ehrbg.
Dendrocoelum lacteum Oerst.
Cercariae with forked rudder tail (in plankton).

Rotatoria and Gastrotricha

Floscularia atrochoides Wierz.
Atrochus tentaculatus Wierz.
Melicerta ringens Schrank.
Conochilus unicornis Rousselet.
Philodina roseola Ehrbg., also alpha-meso-saprobiotic.
" erythrophthalma Ehrbg.
" megalotrocha Ehrbg.
Rotifer tardus Ehrbg.
" bulgaris Schrank, vgl., also alpha-meso-saprobiotic.
" macrurus Ehrbg.
Asplanchna priodonta Gosse, tends to be also oligosaprobiotic.
Synchaeta tremula Ehrbg., tends to be also oligosaprobiotic.
" pectinata Ehrbg. tends to be also oligosaprobiotic.
Polyarthra platyptera Ehrbg. tends to be also oligosaprobiotic.
Triarthra longiseta var limnetica (Zach) =Tr. thranites Skor.
" mystacina Ehrbg.
Taphrocampa selenura Gosse.
Proales tigridia Gosse.
Furcularia gracilis Ehrbg., also alpha-meso-saprobiotic.
" forficula Ehrbg.
" gibba Ehrbg.
" reinhardti Ehrbg., occasionally associated with Stentor coeruleus.
Diglena catellina Ehrbg., also alpha-meso-saprobiotic.
" forcipata Ehrbg., "
Dinocharis pocillum Ehrbg., tends to be also oligosaprobiotic.
" tetractis Ehrbg., "
Scaridium longicaudum Ehrbg.
Stephanops unisetatus Collins.
Diaschiza semiaperta Gosse, also alpha-meso-saprobiotic.
" tenuior Gosse.
Salpina macracantha Gosse.
" mucronata Ehrbg., also alpha-meso-saprobiotic.
Euchlanis triquetra Ehrbg.
Cathypna luna Ehrbg.
Monostyla lunaris Ehrbg.
Lepadella ovalis Ehrbg. also alpha-meso-
Pterodina patina Ehrbg., saprobiotic.
Pompholyx sulcata Hudson.
Noteus quadricornis Ehrbg.
Brachionus militaris Ehrbg., also alpha meso-saprobiotic.
" pala Ehrbg.=B. pala-amphiceros Plate
" urceolaris Ehrbg.
" rubens Ehrbg.
" bakeri Ehrbg.
" angularis Gosse, also alpha meso-saprobiotic.
Anuraea aculeata Ehrbg.
" cochlearis Gosse
} tends also to be oligosaprobiotic.
Notholca striata Ehrbg.
" acuminata Ehrbg.
" labis Gosse.

Lepidoderma rhomboides Stokes
Dasydytes longisetosum Metschnikoff
" zelinkai Lauterborn.
" saltitans Stokes

Bryozoa

Plumatella repens (L.).
" (Alcyonella) fungosa (Pall.).

Mollusca

Limnaea (=Gulnaria) auricularia L., characterized by resistance to some chemical sewage.
" auricularia f. ampla Hartm.
" ovata Drap.
Valvata piscinalis Müll.
Vivipara contecta Millet = V. vera v. Frauenfeld, occurs abundantly also in foul-smelling mud.
" fasciata Müll.
Bythinia tentaculata (L.) Gray, also downstream from sewer outlets.
Lithoglyphus naticoides Ferussac in the Rhine River frequently associated with L. auricularia.
Neritina fluviatilis (L.). the egg capsules were frequently found on the shells of live paludines downstream from sewer outlets.
Unio tumidus Phil.
Sphaerium (=Cyclas) rivicolum Leach
" moenanum Kobelt
Calyculina lacustris Müll.
(tends to be also oligosaprobiotic)

Crustacea

Asellus aquaticus (L.) Ol., also alpha-mesosaprobiotic.
Gammarus fluviatilis Rös., also downstream from sewer outlets and also feeds on Spherotilus.
Cyclops strenuus S. Fischer, also alpha-mesosaprobiotic
Cyclops leuckarti Claus.
Cyclops brevicornis Claus, also alpha-mesosaprobiotic
Cyclops fimbriatus Fischer
Cyclops phaleratus Koch.
(with their development stages)
Diaptomus castor Jurine.
Canthocamptus staphylinus (Jur.), also in drinking-water sand-filters.
Cypridopsis vidua (O.F. Müll.).
Cypria ophthalmica Jurine.
Candona candida (Müll.) and other species
Daphnia pulex Degeer, also alpha-mesosaprobiotic.
" magna Strauss, "
" schaefferi Baird, "
" longispina O.F. Mull.
Moina rectirostris (F. Leydig).
Chydorus sphaericus (O.F. Müll.).
Pleuroxus excisus Schödler.

Hydrachnidae

Limnesia maculata (Müller) Bruzelius.
Arrhenurus bicuspidator Berl., also with Peranema and Euglena viridis.

Tardigrada

Macrobiotus macronyx Duj.

Neuroptera

Anabolia laevis Zett., larvae.
Molanna angustata Curtis, larvae.
Hydorpsyche angustipennis Curtis and larvae of some not accurately determined varieties.
Oxyethira costalis Curtis, larvae.

Diptera

Culex annulatus Fabr., and other species; larvae non-demanding.
Chironomus-larvae of a light yellow but not red color.
Ceratopogon-larvae of not accurately determined varieties.
Simulium ornatum Meig.
" reptans L.
(also alpha-mesosaprobiotic.)

Pisces (the most resistant representatives appear first)

Cobitis fossilis (L.).
Carassius carassius (L.).

Tinca tinca (L.).
Cyprinus carpio L.
Anguilla vulgaris Flem., with the exception of the youth stages.
Rhodeus amarus Bl.
Gasterosteus aculeatus L.
Leucaspius delineatus v. Sieb.
Alburnus lucidus Heck.

Amphibia

Rana esculenta L.
" fusca Rösel
(spawn and tadpoles in part not very sensitive)

III. Oligosaprobia

Rhizopoda

Amoeba proteus Leidy = A. princeps Ehrbg.
Difflugia globulosa Duj.,
" pyriformis Perty,
(also in the beta-mesosaprobiotic zone.)
" urceolata Cart.
" acuminata Ehrbg.
" corona Wallich, also in the beta-mesosaprobiotic zone.
" hydrostatica Zach.
" limnetica Levander and other species.
Lecquereusia spiralis (Ehrbg.)
Euglypha globosa (Cart.) = Sphenoderia lenta Schlumbg.
Cyphoderia ampulla (Ehrbg.) Leidy.
Cyphidium aureolum Ehrbg.
Microgromia socialis Hertw. & Less., also in the beta-mesosaprobiotic zone.

Heliozoa

Rhaphidiophrys pallida F.E. Sch., also in the beta-mesosaprobiotic zone.
Acanthocystis turfacea Cart., also in the beta-mesosaprobiotic zone.

Flagellata

Dimorpha alternans Klebs.
Bicoeca lacustris J.-Cl.
" oculata Zach.
Diplosiga frequentissima Zach.
also in the beta-mesosaprobiotic zone.

Ciliata

Holophrya ovum Ehrbg., also in the beta-mesosaprobiotic zone.
Rhabdostyla ovum Kent.
Lacrymaria olor Ehrbg.
Trachelius elephantinus Svec.
Dileptus trachelioides Zach.
Ophryoglena atra Lieberk.
Frontonia acuminata (Ehrbg.) = O. acuminata & atra Ehrbg.
Strombidium adhaerens Schew. = Str. sulcatum Cl. & L.
" turbo Cl. & L., also in the beta-mesosaprobiotic zone.
Codonella lacustris Ents., also in the beta-mesosaprobiotic zone.
Oxytricha ferruginea Stein.
Stylonychia pustulata Ehrbg., also in the beta-mesosaprobiotic zone.
" histrio (O.F.Müll.).
Vorticella nebulifera Ehrbg.
Carchesium polypinum Ehrbg., also in the beta-mesosaprobiotic zone.
Ophrydium versatile Ehrbg.

Suctoria

Most representatives of this group are probably mesosaprobiotic except for Staurophyra elegans Zach.

Hydroidea

Cf. beta-mesosaprobiotic zone.
Cordylophora lacustris Allm.; lives mainly in brackish water.
Hydra vulgaris Pall. = H. grisea L.
" oligactis Pall. = fusca L.
" polypus L.
" viridis L.

Vermes

Haplotaxis gordioides (G.L. Hartm.) = Phreoryctes menkeanus Hoffm.
Chaetogaster diaphanus (Gruith.), also in the beta-mesosaprobiotic zone.
Gordius aquaticus Duj.
Polycelis cornuta O. Schm.
Planaria gonocephala Dug.
Vortex pictus O. Schm., also in the beta-mesosaprobiotic zone.

Rotatoria and Gastrotricha

Floscularia cornuta Dobie.
Tubicolaria najas Ehrbg.
Asplanchna brightwelli Gosse
Sacculus viridis Gosse, also in the beta-mesosaprobiotic zone.
Triarthra breviseta Gosse
Rattulus capucinus Wierz. et Zach. = Mastigocerca hudsoni Lauterb., also in the beta-mesosaprobiotic zone.
Diurella stylata Eyf. = Rattulus bicornis Western.
Salpina brevispina Ehrbg.
Euchlanis dilatata Ehrbg., also in the beta-mesosaprobiotic zone.
Pompholyx complanata Gosse.
Anuraea hypelasma Gosse.
Notholca foliacea Ehrbg., also in the beta-mesosaprobiotic zone.
" longispina Kellicott
" scapha Gosse.
Gastroschiza flexilis Jaegersk, also in the beta-mesosaprobiotic zone.
Ploesoma truncatum Levander, also in the beta-mesosaprobiotic zone.
Gastropus stylifer Imhof, also in the beta-mesosaprobiotic zone. = Hudsonella pygmaca (Calm.).
Anapus ovalis Bergendal
" testudo Lauterb.
also in the beta-mesosaprobiotic zone.
Schizocerca diversicornis Dod., also in the beta-mesosaprobiotic zone.
Pedalion mirum Hudson
Ichthydium podura O.F. Müller
Chaetonotus maximus Ehrbg., occasionally also beta-mesosaprobiotic; frequent in dry wells; seems little sensitive to H_2S.
Chaetonotus larus O.F. Müller, occasionally also beta-mesosaprobiotic.

Bryozoa

Cristatella mucedo Cuv.
Fredericella sultana (Blumenb.) Gerv.
Paludicella ehrenbergi van Ben.

Mollusca

Limnaea stagnalis (L.) Lam.
" palustris Müll.
" peregra Müll.
also in the beta-mesosaprobiotic zone.
Amphipeplea glutinosa Müll.
Physa fontinalis (L.) Drap.
" acuta Drap.
Aplexa hypnorum L.
Planorbis corneus (L.)Pfeiff.
also in the beta-mesosaprobiotic zone.
" marginatus Drap.
" carinatus Müll. and other kinds.
Ancylus fluviatilis Müll.
" lacustris L.
also in the beta-mesosaprobiotic zone.
Anodonta mutabilis Cless. Some varieties are very resistant.
Margaritana margaritifera L.
Unio pictorum L., often resistant.
" batavus Lam.
Pisidium amnicum Müll.
" fossarinum Cless.

Dreissensia polymorpha Pallas, especially typical for this zone. larvae planktonic.

Crustacea

Astacus fluxiatilis Fabr.
Gammarus pulex (L.)De Geer.
Niphargus puteanus C.L. Koch.
Cyclops viridis Jur.
" albidus Jur.
" serrulatus Fischer, also in the beta-mesosaprobiotic zone.
" bicuspidatus Claus.
" fuscus Jur.
" oithonoides Sars.
Diaptomus gracilis Sars.
" graciloides Lilljeborg.
" laciniatus Lillj.
Eurytemora velox (Lillj.).
Canthocamptus minutus Claus. }
Cypris virens Jurine). } also in the beta-mesosaprobiotic zone.
" incongruens (Ramdohr) }
Sida cristallina (O.F. Müll.).
Diaphanosoma brachyurum (Liévin).
" leuchtenbergianum S. Fischer.
Holopedium gibberum Zaddach.
Daphnia hyalina Leydig with subspecies galeata Sars
" (Hyalodaphnia) cucullata G. O. Sars =kahlbergiensis Schoedler.
Scalopholeberis mucronata (O.F. Müll.).
Simocephalus vetulus (O.F. Müll.) Schoedler.
Ceriodaphnia reticulata (Jur.). also in the beta-mesosaprobiotic zone.
Bosmina longirostris (O.F. Müll.); P.E. Müll. & var. cornuta Jur., also in the beta-mesosaprobiotic zone.
" coregoni Baird.
" " var. gibbera Schoedler.
Acroperus harpae Baird.
Leidigia quadrangularis (Leydig); also in the beta-mesosaprobiotic zone.
Lynceus (Alona) guttatus (Sars.); also in the beta-mesosaprobiotic zone.
" costatus (Sars.); and other species.

Bythotrephes longimanus Leydig.
Leptodora kindti (Focke).

Argyronetidae

Argyroneta aquatica Cl.

Hydrachnidae

Most representatives belong in this zone.
Atax crassipes O.F. Müll. (Bruzelius).
Neumania spinipes Müll.
Curvipes nodatus Müll.
" rufus C.L. Koch.
Hygrobates nigro-maculatus Lebert.
Limnochares holosericea Latreille.

Orthoptera. Larvae.

Libellula depressa L., and other species.
Aeschna grandis L.
Calopteryx virgo L., also in the beta-mesosaprobiotic zone.
Agrion puella L.
Ephemera vulgata L.
Polymytarcis (Palingenia) virgo Ol.
Prosopistoma foliaceum Fourcroy
Baetis species
Heptagenia (Ecdyurus) fluminum Pict.
Cloë diptera L., also in the beta-mesosaprobiotic zone.
Perla bicaudata L.
" nubecula Newm.
Taeniopteryx trifasciata Pict.
Nemura variegata Oliv.

Neuroptera

Phryganea striata L., larvae.
" grandis L., "
Sericostoma, larvae of different species; also beta-mesosaprobiotic.
Brachycentrus subnubilus Curt.; also in the beta-mesosaprobiotic zone.
Leptocerus annulicornis Steph.
Rhyacophila vulgaris Pict.
Hydroptila sparsa Curt.

Hemiptera

Hydrometra lacustris L. }
" rufoscutellata Cuv. } not very suitable for water evaluation
Limnobates stagnorum Cuv. }
Nepa cinera L., rather sensitive to lack of oxygen
Ranatra linearis L., also in the beta-mesosaprobiotic zone.
Aphelocheirus aestivalis Fabr.
Corixa striata L., appears with lack of oxygen under ice first at the "Wuhnen" (colloquial term, possibly meaning hole?).
Notonecta glauca L., somewhat less sensitive to lack of oxygen than Corixa.

Diptera

Corethra plumicornis Fabr., larvae very resistant.

Coleoptera

Dytiscus marginalis L., larvae and beetles; able to follow prey into mesosaprobiotic zone like other predators.
Acilius sulcatus L., larvae and beetles.
Colymbetes fuscus L., larvae and beetles.
Agabus bipustulatus L., larvae and beetles.
Gyrinus natator L., larvae and beetles, not very suitable for water evaluation.
Hydrophilus piceus L., larvae and beetles.

Pisces (the most sensitive representatives are listed first).

Gasterosteus pungitius L.
Esox lucius L.
Lota vulgaris Cuv.
Gobio fluviatilis Cuv.
Scardinius erythropthalmus L.
Blicca björkna L.

Lucioperca sandra L.

Acerina cernua L.
Idus melanotus Heck. & Kn.
Abramis brama L.

Leuciscus rutilus L.
Perca fluviatilis L.
Trutta fario L.

Amphibia

Triton cristatus Laur.
" taeniatus Schneid.

Literature References

Note: The Institute referred to in the text is Kgl. Prufungsanstalt fur Wasserversorgung und Abwasserbeseitigung (Royal Institute for Water Supply and Sewage Disposal).

Note: A number of reports (here given in chronological order) listed below are not specifically referred to in the text but are intended merely as a collection of the widely dispersed pertinent literature.

(1) Lindau, Schiemenz, Marsson, Elsner, Proskauer, Thiesing; Hydrobiological and Hydrochemical Investigations on the Collector Systems of the Bake, Nuthe, Panke and Schwarze. Vol XXI, 1901, Supplement.

(2) Marsson and Schiemenz: Damage to Fishing in the Penne River Through the Sugarmill in Anklam. Vol IX, 1901. No. 1.

(3) Lauterborn, R: Contributions to the Microfauna and Flora of the Moselle River with Special Consideration of Sewage Organisms. Vol. IX, 1901.

(4) Lauterborn, R: The Sapropelic Fauna. Vol. XXIV, 1901.

(5) Kolkwitz and Marsson: Principles for Water Evaluation from Its Fauna and Flora. 1902, No. 1.

(6) Marsson, M: Fauna and Flora of Contaminated Water and Their Inter-relation to Biological Analysis of Water. Vol. X, 1903.

(7) Volk, Rich: Investigation of the Elbe River at Hamburg. Vols XVIII, XIX, XXIII, 1901-1906.

(8) Schiemenz: Organic Sewage Examined in Relation to Fishing. 1901-1907.

(9) Marsson, M: Flora and Fauna of Some Sewage Treatment Stations at Berlin and Their Significance for the Purification of Municipal Sewage. 1904, No. 4.

(10) Marsson, Spitta, Thumm: Expertise on the Permissibility of the Discharge of Fecal Matter into the Main River by the City of Hanau. 1904, No. 5.

(11) Kolkwitz and Thiesing: Chemobiological Investigations on the Use of Trickle Fields for the Purification of Stow-Dam Water for Human Consumption. 1904, No. 5.

(12) Schiemenz: Evaluation of the Purity of Surface Water from Macroscopic Animals and Plants. Vol. XLIX, 1906.

(13) Selk, H: The Algae of the Elbe River and Its Estuary. Vol. XXV, 1907.

(14) Volk, Rich: The Biological Investigation of the Elbe River by the Hamburg Natural History Museum. Vol. XV, 1907.

(15) Kolkwitz, R: Biological Self-Purification and Evaluation of Waters. No. 2, 1907.

(16) Kolkwitz, R: Biology of Caverns, Sources and Wells. No. 37, 1907.

(17) Kolkwitz, R: Instruments for Sampling and Observation in Biological Examinations of Water. No. 9, 1907.

(18) Kolkwitz and Ehrlich: Chemobiological Investigations of the Elbe and Saale Rivers. No. 9, 1907.

(19) Lemmermann: Flagellatae. Vol. III, 1907.

(20) Marsson, M: Four Reports on the Biological Investigation of the Rhine River Between Mayence and Coblentz. 1907 and 1908.

(21) Lauterborn, R: Four Reports on the Biological Investigation of the Rhine River Between Basel and Mayence. 1907 and 1908.

(22) Kolkwitz and Marsson: Ecology of Plant Saprobia. Vol. XXVIa, 1908, pp. 505-519.

(23) Kolkwitz, Pritzkow and Schiemenz: Two Expertises on the Sewage and Outflow Conditions of a Cellulose Plant Near Kattowitz. No. 10, 1908.

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VALUE OF THE BOTTOM SAMPLER IN DEMONSTRATING THE EFFECTS OF POLLUTION ON FISH-FOOD ORGANISMS AND FISH IN THE SHENANDOAH RIVER

Crosswell Henderson
U. S. Fish and Wildlife Service
Kearneysville, West Virginia

IN THE PAST several years legislation and activity directed toward the control and abatement of stream polution have greatly increased. Numerous States have passed legislation forming water commissions, water-control boards, or other groups or committees to deal with stream pollution within their borders. Some States have formed interstate agencies to deal with activities in a particular river basin. The passage of Public Law 845 greatly increased activities from a national viewpoint.

All these groups have at sometime or another been concerned with stream surveys to determine extent or degree of pollution. Many groups have worked on this problem and have come up with varied answers. Some have set arbitrary standards of cleanliness, below which no body of water would be allowed to degrade. Others have classified streams into groups (A, B, C, D, etc.) depending on usage and have set standards of cleanliness to be maintained in each class. Still others have set no standards but have treated each pollution problem separately and have had a board to decide the degree of pollution that would be allowed. Unfortunately, little or no consideration has been given to fish or wildlife in many of these surveys or classifications. For many years sportsmen's groups have been fighting for clean streams, and these groups have been instrumental in causing the enactment of much of the constructive pollution legislation. Yet, when pollution is discussed at various meetings and standards are set for streams, practically nothing is heard about what aquatic life (other than bacteria) is in, or should be maintained in a stream.

For a great many streams there is a wealth of information as to the coliform bacteria count, the biochemical oxygen demand, total solids, color, odor, and other factors; but there is very little information as to what fish or fish-food organisms may be present. True, most of these pollution surveys have been made from the standpoint of public health or for municipal or industrial water supplies--which are, of course, very important. But why not include in these surveys some data as to the effects of pollution on normal aquatic life?

Requirements for water to drink or to operate an industry may be vastly different from the requirements for the maintenance of fish and aquatic life. Water from an open sewer would certainly be unfit to drink but, if not in such excessive quantity as to use all the oxygen in the receiving stream, may even have a beneficial effect (through fertilizer values) on aquatic life. Water suitable for industrial use may have small quantities of some toxic substance which would make that water deadly to aquatic life.

Aquatic life in streams may be depleted generally in four ways: (1) lack of dissolved oxygen, (2) too high or too low hydrogen-ion concentration, (3) smothering effect of silt or other fine material, (4) the presence of definitely toxic substances. In general, most pollution surveys would demonstrate the first two of these conditions. Dissolved oxygen and pH are standard tests used in pollution surveys, and the requirements of most aquatic animals are known. The third may show up in observations or from turbidity determinations. The fourth condition would become apparent only through elaborate chemical tests and a knowledge of the toxicity of numerous substances to the various aquatic animals.

Simple methods of determining the effects of the third and fourth factors are based upon use of a Surber (1937) square-foot bottom sampler (figure 1) in gravel and rubble, and Ekman or Peterson dredges in mud or silt. Stream bottoms are normally the habitat for numerous aquatic insect larvae and other aquatic animals. These forms may include the larvae of May flies (Ephemerida), stone flies (Plecoptera), dragonflies (Anisoptera), damsel flies (Zygoptera), midge flies and crane flies (Diptera), caddis flies (Trichoptera), dobson flies (Neuroptera), and other aquatic animals such as water beetles (Coleoptera), aquatic earthworms (Oligochaeta), crayfish and shrimp (Crustacea), and snails and clams (Mollusca). These are the principal fish-food organisms. Square foot bottom samples taken in riffles above and below sources of pollution show immediately the approximate quantity and the types of fish-food organisms present. Without sufficient quantities of these animals, fish soon disappear for lack of food, whether they can survive in the water or not.

Though all of the physical, chemical, and bacteriological determinations normally used in any stream evaluation are quite important, there is frequently a definite lack of biological determination to show the actual impact of pollution on aquatic life in the stream. This has been forcibly pointed out by Beatty (1947). Ellis and Westfall (1946) and Hart, Doudoroff, and Greenbank (1945) established uniform bioassays or toxicity experiments which could be used to show toxicity levels of various chemicals and wastes for fishes. Though such tests are very useful, there may be great differences between laboratory toxicity tests and actual conditions in streams. Other workers, including Platner (1946), Wiebe (1928), and Ellis (1940), used Peterson dredges and bottom samplers of various kinds to determine the biological impact of pollution.

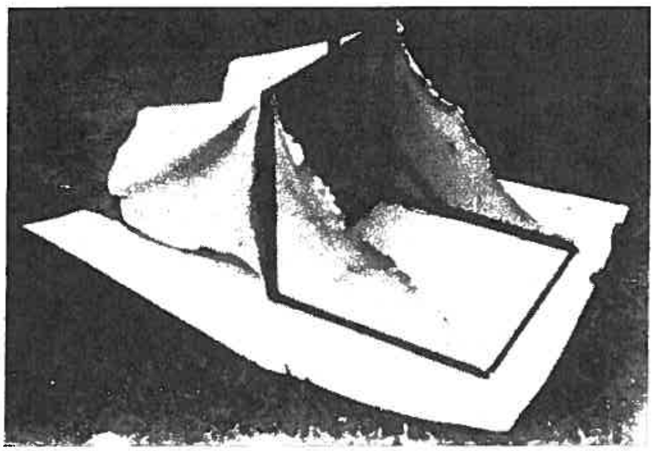


Figure 1 - Surber square-foot bottom sampler.

Methods for the collection and microscopical examination of plankton have been known and used for many years. Many workers, including Lackey (1940), McGauhey (1942), and Purdy (1930), have applied these methods to pollution studies, in which certain types of protozoan plankton and other microscopic organisms were used as indicators of stream pollution.

In a study of pollution of the Coeur D'Alene River, Ellis (1940) called attention to the presence of large numbers of bottom animals, such as caddis-fly larvae and stone-fly and May-fly nymphs, in riffle areas above sources of pollution -- and their complete absence below these sources. Surber (1939) used a square-foot bottom sampler of a new, compact design in sampling four eastern smallmouth-bass streams to determine the fish-food organisms present. This work led to the use of this bottom sampler in pollution studies in the Shenandoah River.

PURPOSE OF INVESTIGATIONS

The Shenandoah River was for a long time the favorite fishing ground of numerous residents of northern Virginia and the eastern panhandle of West Virginia. In fact, this river was so noted as a smallmouth-bass stream that sportsmen were attracted from all over the eastern United States to try their luck at catching the elusive bass. In 1940, a large corporation, the American Viscose Company, began operations at Front Royal, Virginia, on the South Fork of the Shenandoah just above the confluence with the North Fork. Though a clean stream was promised the sportsmen of this section, it was only a short time until fishing in the main Shenandoah had declined considerably. Numerous dead fish were seen in the river during the winter of 1942-43. Sportsmen became alarmed and called upon the Fish and Wildlife Service to determine the condition of the river. Bottom samples taken above and below the Viscose plant showed more than 99 percent decrease in bottom animals 30 miles below the plant, as compared with the number immediately above. This fact was reported to the Virginia Commission of Game and Inland Fisheries in August 1943, but little could be done because of very weak pollution laws. Further fish kills were observed in the winters of 1943-44 and 1944-45, when sport fishing had practically ceased to exist on the main river. About this time, Izaak Walton League chapters were formed in Winchester and Berryville, Virginia, with the cleanup of the Shenandoah River their main objective. These and other nearby chapters sponsored an investigation to determine sources and degree of pollution and its effects on aquatic life in the river: the facts obtained in this study were to be used in making the general public aware of existing conditions. This study was started in June 1947 and was continued throughout the summer. This survey was continued through 1948 by the Fish and Wildlife Service from its Fishery Station at Leetown, West Virginia. Investigations are still under way. This paper is not a complete report of work on the Shenandoah but is undertaken at this time to show certain correlations of numbers and types of bottom animals to pollution, and to show the desirability of using the Surber bottom sampler more widely as a tool in stream pollution surveys.

DESCRIPTION OF RIVER

The Shenandoah River (figure 2) rises in the mountains of northern Virginia, the North Fork in the Allegheny Mountains and the South Fork in the Blue Ridge. Massanutten Mountain separates the two forks. Each fork, fed intermittently by mountain streams and limestone springs, flows a distance of some 150 miles through fertile limestone valleys to Front Royal, Virginia. From the confluence of the forks at Front Royal, the main Shenandoah flows north about 60 miles along the foot of the Blue Ridge Mountains, entering the Potomac River at Harpers Ferry, West Virginia. The lower 20 miles of the river are in West Virginia.

This river is normally a clear, fast-flowing, fertile stream. Extensive riffle areas and limestone ledges serve to make ideal food and cover conditions for fish.

Surber, comparing the Shenandoah River (main stream) with other smallmouth-bass streams in this area (1939), found the growth of bass to be very rapid: the bass reached legal length (10 inches) in 2 to 3 years. Food conditions were reported to be excellent, as there was an abundance of forage fish and bottom animals.

Prior to 1940, the whole Shanandoah River system was considered a mecca for fishermen. Residents of

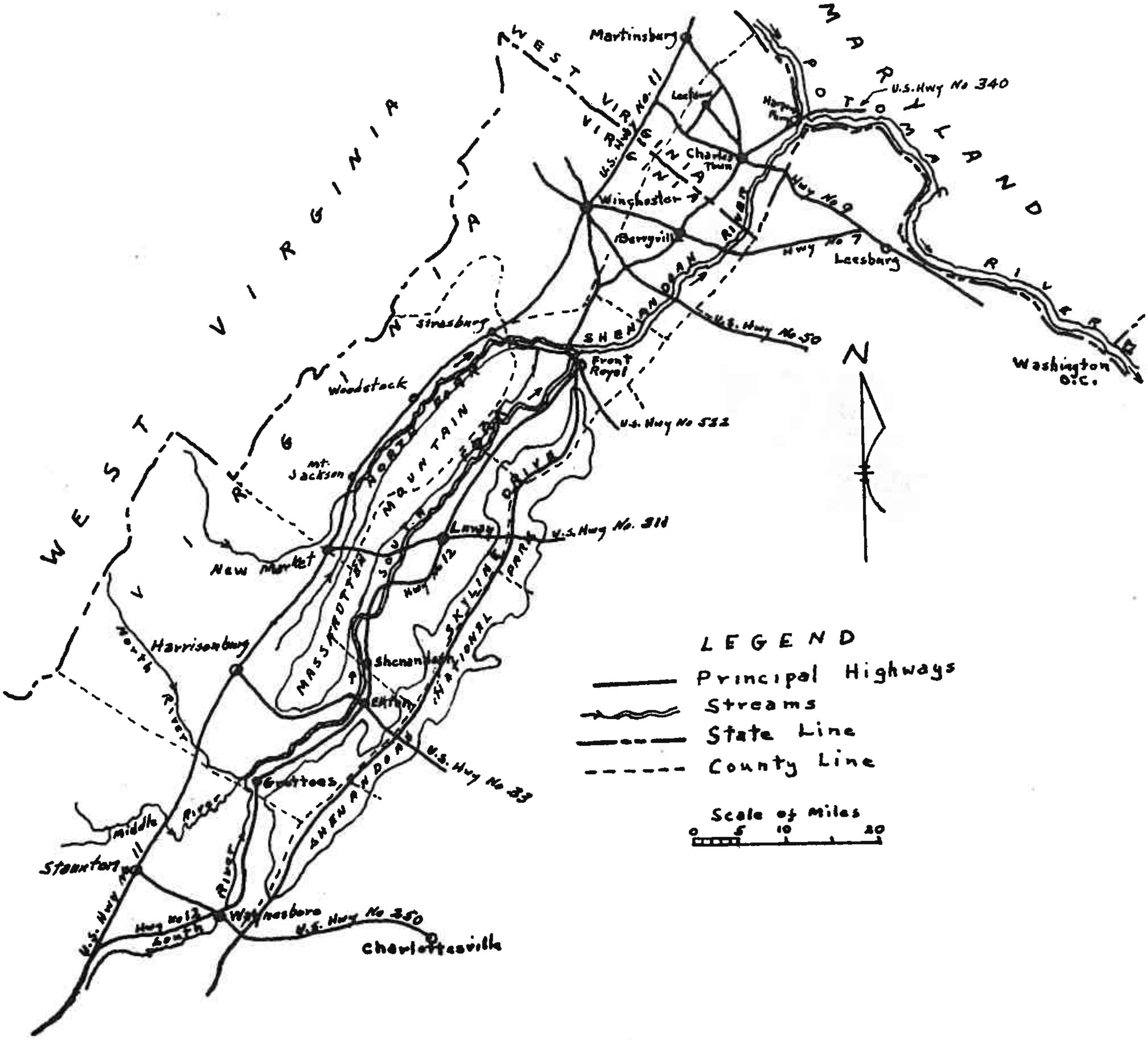


Figure 2 - The Shenandoah River System.

this area claim that as a smallmouth-bass stream it could not be surpassed. Excellent fishing occurred in practically all of the river. The principal species taken were smallmouth bass, largemouth bass, yellowbelly sunfish, channel catfish, carp, suckers, and crappie.

POLLUTION IN THE SHENANDOAH RIVER SYSTEM

Preliminary surveys disclosed no serious sources of pollution (from the fishery standpoint) in the North Fork. Several small towns (Woodstock, Strasburg, and others) discharged raw sewage into the river, but the dilution factor was such that there were no detrimental effects to aquatic life; so the North Fork was not included in this survey.

Three streams--South River, Middle River, and North River--meet just above Port Republic, Virginia, to form the South Fork of the Shenandoah. At Waynesboro, South River receives a serious load of pollution from industries and sewage from the town itself. Fish kills have been reported to the Virginia Game Commission several times. At present, the Virginia Water Control Board is making a study of this part of the river. Owing to this and to the fact that this portion of the river was not considered important for sport fishing, it was not included in this investigation. The remainder of the Shenandoah River system was included (figure 3).

Preliminary bottom samples showed no apparent effect on aquatic life from the sewage of the four towns; so this study was confined primarily to the effect of industrial wastes from the Merck Chemical Company and the American Viscose Corporation plants.

It was suspected that the Viscose effluent contained one or more substances that were deadly to aquatic animals and that this material persisted in the water for a considerable distance downstream. From a study of materials used at the Viscose Corporation plant in

Figure 3 - Study stations and sources of pollution.

Sources of pollution:

A -- The Merck Chemical Company, Elkton, Virginia: manufactures streptomycin, vitamin B_1, and other chemicals; empties wastes (nature of which is not definitely known) directly into the South Fork of the Shenandoah River; has facilities for waste treatment.

B -- Domestic sewage from the town of Elkton, Virginia: population, 1,500; untreated wastes empty directly into the river.

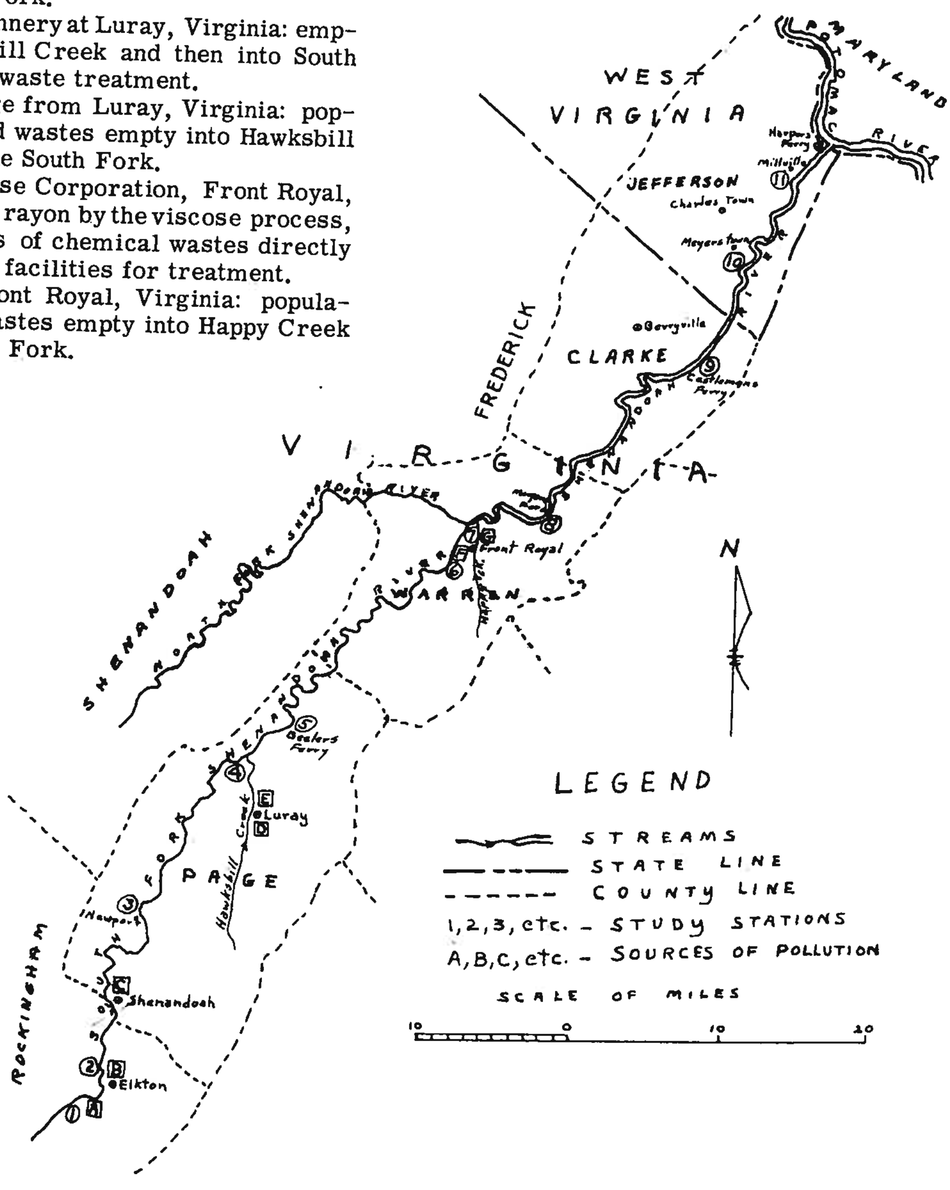
C -- Domestic sewage from the town of Shenandoah, Virginia: population, 1,000; untreated wastes empty directly into the South Fork.

D -- Virginia Oak Tannery at Luray, Virginia: empties wastes into Hawksbill Creek and then into South Fork; has facilities for waste treatment.

E -- Domestic sewage from Luray, Virginia: population, 1,100; untreated wastes empty into Hawksbill Creek and thence into the South Fork.

F -- American Viscose Corporation, Front Royal, Virginia: manufactures rayon by the viscose process, empties large quantities of chemical wastes directly into the South Fork, has facilities for treatment.

G -- Sewage from Front Royal, Virginia: population, 5,200; untreated wastes empty into Happy Creek and thence into the South Fork.



making rayon by the Viscose process (Roetman 1944) and a review of the literature concerning toxicity of various substances to aquatic animals (Ellis 1937), several substances -- among them, xanthates, hydrogen sulphide, and zinc -- were immediately suspected. Xanthates were largely eliminated because of assurance by Viscose Corporation officials that this material could not possibly reach the river and because xanthates could not exist in the effluent under acid conditions. (The effluent was highly acid (pH 2.4) at least at times during the period of major destruction of aquatic animals in the river.) Hydrogen sulphide, though present in toxic quantities in the effluent, was probably eliminated as a result of aeration in the riffle areas of this fast-flowing river. Analysis of the viscose effluent showed zinc to be present in quantities above 2,000 parts per million. In England several workers with lead and zinc mine pollution had shown zinc in quantities as low as 0.2 parts per million to be lethal to some aquatic animals (Newton 1944). Analysis of the water below the Viscose Corporation showed zinc to be present in quantities considerably above this value: tests revealed the presence of zinc at the rate of 0.4 to 11 parts per million, depending on river flow and other conditions. Zinc was thus indicated as at least one of the major factors contributing to the destruction of aquatic life in the river.

Laboratory toxicity experiments were made with both Viscose effluent and pure zinc sulphate to determine the effects on fish and other aquatic animals. It was determined that the Viscose effluent (in concentrations simulating low water and normal river conditions) was deadly to at least some kinds of aquatic animals, and that zinc itself (in quantities present in the river) was toxic to some aquatic animals, such as bass fry, daphnia, and snails. The results of this work with zinc led Viscose officials to set up their own toxicity work with zinc and to put major emphasis on the elimination of zinc from their effluent.

Since the construction of the Viscose Corporation plant in 1940, that organization has expended considerable amounts of effort and money to work out processes for treatment of waste (Roetman 1944). Until 1948, however, the Viscose effluent was treated only a part of the time, and this treatment was entirely inadequate insofar as the aquatic life in the river was concerned. As a result of the publicity received in connection with this study that showed the river to be virtually devoid of aquatic life, the Viscose Corporation has made further effort to improve the treatment of its effluent and has done additional work in reducing the zinc content of that effluent. Reports (April 6, and December 6, 1948) to the Virginia Water Control Board showed much improvement in treating the effluent. At the present writing (June 1949) considerable progress seems to have been made. Complete treatment (ordered by the Virginia Water Control Board to be in effect by March 1949) has been in effect for some time, and the river appears to be recovering.

SAMPLING STATIONS

Eleven study stations (table 1, figure 3) were established at accessible riffle areas above and below possible sources of pollution. Physical, chemical, and biological determinations were made at each station once each month from June to October 1947, and in June and September 1948. These determinations were made at low-water or normal river stages.

PHYSICAL AND CHEMICAL CONDITIONS

Water temperature, hydrogen-ion concentration, dissolved oxygen, free carbon dioxide, and methyl-orange alkalinity (table 2) were determined by standard methods of water analysis (American Public Health Association 1946). Other physical and chemical data were obtained from the West Virginia Water Commission (table 3).

BIOLOGICAL CONDITIONS

In riffle areas near each station, bottom samples were taken with a square-foot bottom sampler used in the manner described by Davis (1938). Square-foot bottom samples were collected, sieved, and preserved in formalin. The animals were later picked out, identified to order, counted, and weighed (wet weight after draining 45 seconds). (See tables 4 and 5.)

ANALYSIS OF DATA

Physical and chemical conditions in the Shenandoah River (tables 2 and 3) are such that by accepted standards (Ellis 1937) the water would be deemed satisfactory to support nearly all forms of aquatic life. In only a very few instances, and then only for short distances below sources of pollution, were dissolved oxygen and pH values such that a good mixed aquatic fauna could not be maintained. Dissolved oxygen values as low as 3.9 parts per million occurred at Station 2 (3 miles below Merck Company) during low water in the summer of 1947 and averaged 5.9 parts per million for the summer, but at Station 3 (less than 20 miles downstream) dissolved oxygen values averaged 8.4 parts per million and at no time were less than 6 parts per million. At no time was a value for dissolved oxygen at Station 1 (above Merck Company) found below 6 parts per million. This tended to show a definite oxygen demand by Merck Company wastes and indicated that conditions below would be somewhat hazardous to certain organisms requiring high oxygen content of water. Bottom-animal samples (table 4, figure 4) appeared to substantiate this belief. Samples at Station 1 contained an average of 912 bottom animals weighing 6.5 grams, while samples at Station 2 averaged only 108 bottom animals weighing 0.42 gram. Samples at Station 3 (25 miles below Merck Company) averaged 528 bottom animals weighing 4.13 grams. A major portion of the bottom animals at Station 2 consisted of oligochaete worms, leeches, and midgefly larvae (animals having low oxygen requirements); while at Stations 1 and 3 there was an abundance of caddis-fly larvae and May-fly nymphs and other types (table 5) which generally require high oxygen content of the water.

Reports from fishermen also tend to substantiate this conclusion. Though carp (fish having low oxygen

TABLE 1.--Station numbers, approximate location, miles between stations, and stream-flow data

Station No.	Location of stations	Miles from Station 1	Stream flow[1/] cubic feet per second 1930-42 average Ave.	Min.	Min. daily
	South Fork, Shenandoah				
1	1 mile above Merck Co., 4 miles south of Elkton, Va.	-	974	32	93
2	3 miles below Merck Co., Elkton, Va.	4	-	-	-
3	25 miles below Merck Co., Newport, Va.	26	-	-	-
4	1 mile above Hawksbill Creek, Shenandoah Lodge, Va.	43	-	70	135
5	5 miles below Hawksbill Creek, Beelers Ferry, Va.	50	-	-	-
6	1 mile above Viscose Co., Front Royal, Va.	86	-	-	-
7	1 mile below Viscose Co., Riverton, Va.	88	1,713	59	103
	Shenandoah River				
8	10 miles below Viscose Co., Morgans Ford	97	-	-	-
9	30 miles below Viscose Co., Castlemans Ferry	119	-	-	-
10	40 miles below Viscose Co., Meyerstown, W. Va.	129	-	-	-
11	50 miles below Viscose Co., Millville, W. Va.	137	2,453	59	194

[1/]Stream-flow data from Geological Survey Water Supply Paper 951.

requirement) were caught quite often in the vicinity of Station 2, few bass were taken. On the other hand, reports showed bass fishing fair to good near Stations 1 and 3.

The low oxygen conditions existing in the summer of 1947 have evidently been corrected. Samples taken in 1948 (table 2) show dissolved oxygen values well above those expected to support a good mixed aquatic fauna. Bottom animals (table 4) have also shown a remarkable recovery in this section of the river and are now present in numbers and weights similar to what would be expected in unpolluted sections of this stream. Certain of the important types such as May-fly nymphs, however, have not yet appeared (table 5). Caddis-fly larvae and hellgrammites have become very abundant.

From Station 3 to Station 6, the river shows little variation in physical and chemical qualities (table 2). All values are well within the limits that may be expected to support a good aquatic fauna. Bottom animals of types expected were abundant in all riffle areas examined in this section of the river (tables 4 and 5). At the beginning of this study, it was expected that wastes from the tannery and sewage from Luray would have some detrimental effect on the river. Field tests, however, did not substantiate this idea. Chemical and biological conditions appeared as good below this possible source of pollution as above. Consequently, Station 4 was eliminated as a study station. Fish kills in Hawksbill Creek were reported to the Virginia Game Commission late in 1947, but no detrimental effects were shown in the Shenandoah, possibly because of dilution.

TABLE 2.--Average, maximum, and minimum values of temperature, dissolved oxygen, pH, free carbon dioxide, and methyl-orange alkalinity, Shenandoah River

Station No.	Water temperature (°F.) Ave.	Water temperature (°F.) Max.	Water temperature (°F.) Min.	Dissolved oxygen (p.p.m.) Ave.	Dissolved oxygen (p.p.m.) Max.	Dissolved oxygen (p.p.m.) Min.	pH Ave.	pH Max.	pH Min.	Free carbon dioxide (p.p.m.) Ave.	Free carbon dioxide (p.p.m.) Max.	Free carbon dioxide (p.p.m.) Min.	Methyl-orange alkalinity (p.p.m.) Ave.
	1938 (May 1 to October 31, 5 samples)[1]												
9	71			9.0			8.2			0.5			116.5
	1947 (June to October, 5 samples)												
1	69	76	54	7.5	10.3	6.1	7.9	8.0	7.9	2	5	0	
2	71	77	56	5.9	8.7	3.9	7.7	7.9	7.5	3	2	6	
3	72	80	56	8.4	10.6	6.0	7.9	8.0	7.7	0	0	0	
5	74	81	64	9.8	11.3	9.1	8.3	8.6	8.0	0	0	0	
6	76	85	64	10.3	12.8	8.1	8.6	9.2	8.2	0	1	0	
7	79	89	66	7.2	9.4	4.4	5.8	7.4	4.4	65	94	10	
8	78	87	64	8.5	9.4	6.3	7.9	8.2	7.2	0	0	0	
9	78	88	62	8.6	9.6	6.0	8.0	7.7	8.2				
10	-	88	-	8.2	-	-	7.9	-	-				
11	-	88	-	7.7	-	-	8.1	-	-				
	1948 (June 23 and September 29, 2 samples)												
		June	Sept.		Sept.	June		June	Sept.		June	Sept.	
1	68	74	61	8.2	9.1	7.4	8.0	8.1	8.0	0	0	0	145
2	68	74	62	7.0	7.9	6.0	8.0	8.0	7.9	1	2	1	140
3	70	78	62	9.1	9.2	9.0	8.4	8.8	8.0	0	0	0	130
5	71	80	63	9.4	10.0	8.8	8.3	8.5	8.2	0	0	0	131
6	75	82	68	10.2	11.0	9.4	8.5	8.7	8.3	0	0	0	121
7	77	85	69	9.2	10.2	8.2	8.0	8.3	7.7	5	10	0	108
8	75	82	68	9.3	9.9	8.8	8.3	8.7	8.0	0	0	0	126
9	72	79	66	7.9	9.1	6.8	8.2	8.2	8.2	0	0	0	114
10	74	81	64	8.6	9.2	8.1	8.3	8.5	8.1	0	0	0	125
11	76	87	66	8.1	9.0	7.3	8.3	8.5	8.0	0	0	0	123

[1] Surber, E. W. (1938 data).

TABLE 3.--Shenandoah River stream-survey data furnished by West Virginia Water Commission

	Source of sample								
	Point 1[1]			Point 2[2]			Point 3[3]		
Date of sample (1947)	8/29	9/5	9/12	8/29	9/5	9/12	8/29	9/5	9/12
Laboratory number	44	44	44	43	43	43	42	42	42
Water temperature, °F.	80	79	82	82	78	80	80	80	85
Dissolved oxygen,									
p.p.m.	9.7	7.65	9.75	8.25	7.35	7.7	7.25	6.95	7.9
percent saturation	119	93	122	104	89	95	89	85.5	102
Bio-chemical oxygen demand, p.p.m.	0.5	0.7	0.85	0.5	0.75	1.2	0.5	0.6	1.5
Hydrogen-ion concentration (pH)	8.15	8	8.35	8.28	8.45	8.35	8.2	8.2	8.4
Alkalinity[4]									
methyl orange	100	112	116	117	119	115	121	120	111.5
phenolphthalein	-0.5	-0.5	2	Neut.	5	2.5	Neut.	3	1.5
Chlorides, p.p.m.	10.5	10	14	10	11	12	11.5	10.5	11
Hardness, p.p.m.	141	162	171	149	152	156	160	166	170
M.P. No. Coliform organisms X 1000	<0.11	0.026	<0.11	<1.1	0.026	0.11	<1.1	1.5	0.89

1/ Rt. 7, east of Berryville, Virginia. Corresponds to Station 9.
2/ Rt. 9, east of Charles Town, West Virginia. Corresponds to Station 10.
3/ Millville, West Virginia. Corresponds to Station 11.
4/ Negative alkalinity indicates acidity.

TABLE 4.--Average, maximum, and minimum numbers of bottom animals at each station

Station No.	Bottom animals: Number per square foot Ave.	Max.	Min.	Grams per square foot Ave.	Max.	Min.	Pounds per acre Ave.
	1936 (August, 10 samples)						
9	203			10.05			942
	1943 (August, 5 samples)						
6	417			7.45			698
9	4			0.08			7
	1947 (June to October, 5 samples)						
1	912	1,420	340	6.50	10.25	2.18	611
Merck Co.							
2	108	187	78	0.42	1.05	0.18	40
3	528	634	440	4.13	5.01	2.75	390
5	628	866	466	10.55	13.90	4.76	990
6	590	781	325	18.56	23.60	14.45	1,752
Viscose Co.							
7	0	0	0	0	0	0	0
8	70	221	1	0.62	1.50	0.10	59
9	32	92	5	0.12	0.20	0.01	11
10[1/]	2			0.05			5
11[2/]	19	20	18	0.10	0.10	0.10	10
	1948 (June and September, 2 samples)						
1	1,362	1,469J[3/]	1,255S[4/]	6.45	7.06J	5.83S	604
2	560	871S	250J	4.07	7.94S	0.20J	381
3	566	675J	458S	1.97	2.39J	1.55S	185
5	714	927S	501J	18.95	20.78J	17.13S	1,776
6	937	1,200S	674J	17.60	27.43S	7.78J	1,649
7	0	0	0	0	0	0	0
8	85	150J	20S	0.29	0.33S	0.25J	27
9	270	367J	172S	0.32	0.42S	0.23J	30
10	187	301J	74S	0.40	0.69J	0.10S	37
11	362	600J	124S	0.64	0.80J	0.48S	60

1/ One sample only.
2/ Two samples only.
3/ J - June.
4/ S - September.

This section from Station 3 to Station 6 (approximately 60 miles) is known far and wide as an excellent smallmouth-bass stream. Many excellent catches of bass, as well as sunfish, channel catfish, and other fishes, are taken during the fishing season.

From Station 7 to its mouth (55 miles), the Shenandoah presents an entirely different picture. Although standard physical, chemical, and bacteriological tests (tables 2 and 3) showed nothing seriously wrong, bottom samples taken in the summer of 1947 (table 4) showed this section of the river to be virtually devoid of aquatic life.

It is possible that, while this section (Station 7 to the mouth) is wholly unfit for fishing, values obtained from standard stream surveys (table 3) would place it in a very high category (Class A, West Virginia Water Commission, 1948). Bottom samples (table 4), however, have shown the marked depletion of aquatic life in this stream. At Stations 8, 9, 10, and 11, values for temperature, dissolved oxygen, pH, turbidity, and carbon dioxide (table 2) have consistently remained within limits that may be expected to support a good aquatic fauna. At Station 7, values for dissolved oxygen and pH were below recognized limits for a short time in the summer of 1947 but have since remained within the desired limits.

Bottom samples (tables 4 and 5) have shown that, though bottom animals of most desirable types were abundant at Station 6 (1 mile above Viscose), in no instances were any bottom animals found at Station 7 (1 mile below Viscose). Samples taken at Stations 8, 9, 10, and 11 showed bottom animals to be extremely limited in both number and desirable type (figure 4).

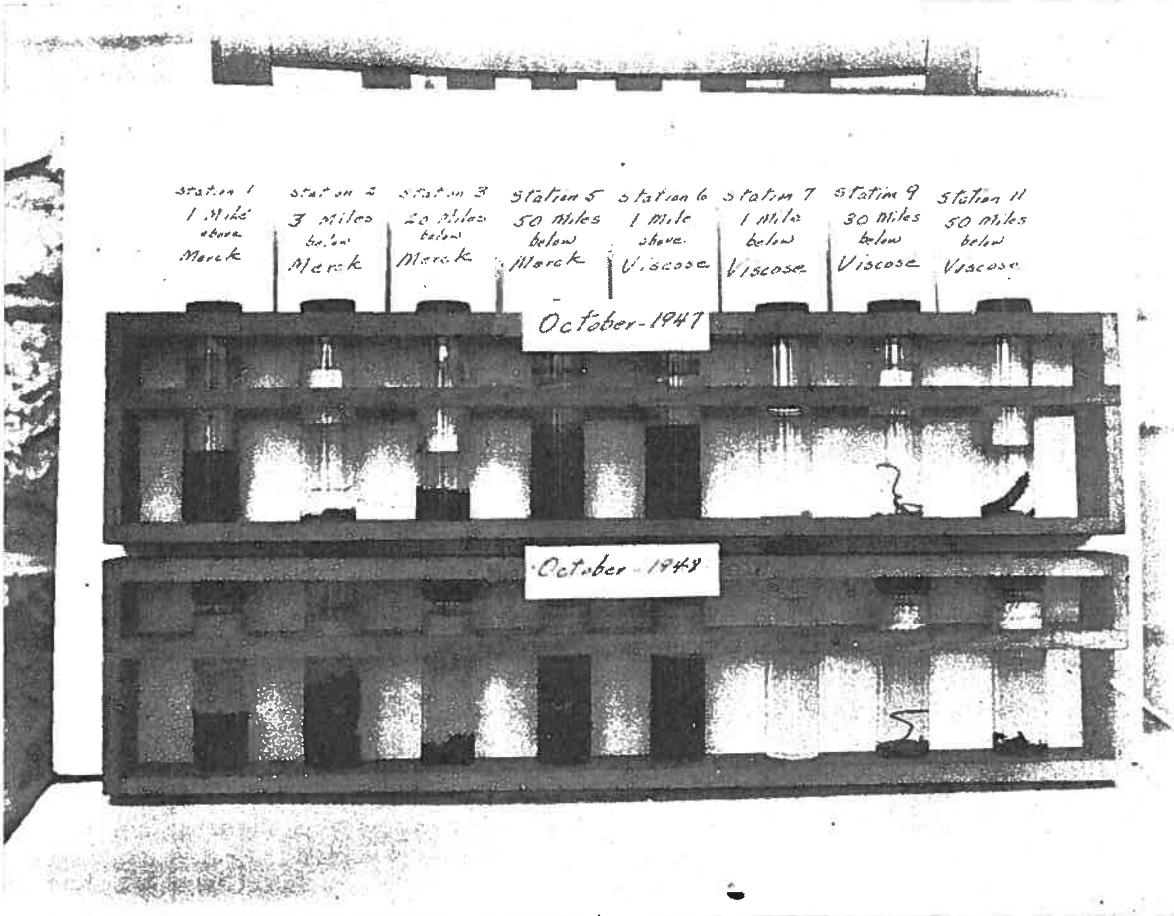


Figure 4 - Bottom animals in square-foot samples.

In August 1943, examining 5 bottom samples taken at Station 6 and 10 samples taken at Station 9 (table 4), Surber found bottom animals at Station 9 reduced 99 percent in average number and 97 percent in weight. The data from Station 9, as compared with data taken at the same station in 1936 (before pollution), showed a reduction of 98 percent in average number and 99 percent in average weight of bottom animals.

Bottom samples taken in the summer of 1947 showed practically the same conditions existing then as in 1943. Samples in 1948 showed a considerable increase in number and a slight increase in weight. This increase, however, consisted almost entirely of midge-fly larvae (Chironomus sp.). Other important fish-food forms, such as hellgrammites, caddis-fly larvae, and May-fly nymphs, have not yet appeared in any degree of abundance.

Though observations in 1947 did not disclose the presence of minnows in the lower river, in 1948 minnows were observed to be present at Stations 8 and 9 and fairly abundant at Stations 10 and 11.

Although fishing in this stream is still extremely limited, reports from fishermen in the summer of 1948 showed that sunfish, channel catfish, and carp were found in the vicinity of Stations 9 and 10. No reports of bass being caught in this section of stream were received, but several small bass (4 to 5 inches) were observed at Station 10.

A fair number of fishermen were observed at Station 11 during the summer of 1948. Though most fishermen considered fishing very poor, quite a few catches of sunfish, channel catfish, and carp--and even a few bass--were reported.

Though some improvement (both chemical and biological) has been made in the lower river, number and types of bottom animals still show a serious state of depletion. No mollusks and very few of the other major fish-food organisms are present (table 5). Until these bottom-animal conditions improve considerably, and until further field studies (including bottom samples) verify such improvement, it cannot be assumed that this section of the river is free of serious pollution.

CONCLUSIONS

1. Pollution surveys ordinarily contain no measure of fish-food organisms or fish in a stream.
2. Standard physical, chemical, and bacteriological methods used in pollution surveys do not necessarily present the true picture with respect to fish and other aquatic animals.
3. The lower Shanandoah River affords an example

TABLE 5.--Average number and kinds of bottom animals per square foot

Station No.	Aquatic earthworms	May-fly nymphs	Midgefly larvae	Caddis-fly larvae	Beetle larvae	Hellgrammites	Snails	Misc.	Total
	1937 (June to September, 141 samples)[1]								
9	1.7	46.8	16.4	37.4	14.8	3.8	6.8	4.8	132.5
	1947 (June to October, 5 samples)								
1	1	171	176	458	83	1	4	18	912
2	27	0.4	56	7	3	0.2	21	3	108
3	1	44	56	389	5	2	25	5	528
5	0.5	175	89	217	29	2	104	11	628
6	0.2	137	83	156	73	6	129	5	590
7	0	0	0	0	0	0	0	0	0
8	0	3	59	0.8	6	0.4	0	0.6	70
9	0.6	0	30	0	1	0.6	0	0	32
10	0	0	0.5	0	0	0.5	0	0	1
11	0	0	16	0	2	0	0	1	19
	1948 (June to September, 2 samples)								
1	3.5	196	271	766	87	3	11	24	1,362
2	0	2	349	174	10	1.5	23	1	560
3	0.5	22	192	331	1	2	12	5	566
5	5	269	26	162	26	2.5	186	38	714
6	0.5	473	163	158	41	7.5	77	17	937
7	0	0	0	0	0	0	0	0	0
8	1	1	80	1	2	0	0	0	85
9	4	0	262	1	2	0	0	1	270
10	1	0	185	0	1	0	0	0	187
11	0.5	3	348	8	1	1	0	0	362

[1] Surber, E. W. (1942).

of a large stream that is relatively free of pollution according to accepted physical, chemical, and bacteriological standards, yet contains virtually no fish or other aquatic animals because of toxic elements from industrial wastes.

4. The Surber bottom sampler is a tool which may be used, in the Shenandoah River and in similar streams, to determine the impact of pollution on fish-food organisms and consequently on fish. By the simple method of using this sampler, the source, degree, and extent of pollution may be determined.

LITERATURE CITED

American Public Health Association
1946. Standard methods of wateranalysis. American Public Health Association, New York, 9th ed., 286 pp.

Beatty, R. O.
1947. Pollution, pollution abatement and the wildlife crop. Izaak Walton League of America, Chicago, Ill., 36 pp.

Davis, H. S.
1938. Instructions for conducting stream and lake surveys. U.S. Bur. Fish., Fish. Circ. 26, 55 pp., illus.

Ellis, M. M.
1937. Detection and measurement of stream pollution. U.S. Bur. Fish. Bull. 22, 72 pp., illus.

1940. Pollution of the Coeur D'Alene River and adjacent waters by mine wastes. U.S. Fish and Wild. Serv., Spec. Sci. Rept. 1, 61 pp.

--- Westfall, B. A.; and Ellis, M. D.
1946. Determination of water quality. U.S. Fish and Wild. Serv., Res. Rept. 9, 117 pp.

Hart, W.B.; Doudoroff, Peter; and Greenbank, John.
1945. The evaluation of the toxicity of industrial wastes, chemicals and other substances to freshwater fishes. Waste Control Lab., Atlantic Refining Co., Philadelphia, Pa., 317 pp.

Lackey, J. B.
1940. Limitations of Euglenidae as polluted water indicators. Pub. Health Repts. 55 (7): 268-280

McGauhey, P. H.; Eich, H.F.; Jackson, H.W.; and Henderson, Croswell.
1942. A study of the stream pollution problem in the Roanoke, Virginia, metropolitan district. Va. Poly. Inst., Eng. Expt. Sta., Series 51.

Newton, Lilly
1944. Pollution of rivers of West Wales by lead and zinc mine effluent. Annals, Applied Biology 31: 1-11.

Platner, W.S.
1946. Water quality studies of the Mississippi River. U.S. Fish and Wild. Serv. Spec. Sci. Rept. 30, 77 pp.

Purdy, W.C.
1930. A study of the pollution and natural purification of the Illinois River. Pt. 2, The plankton and related organisms. Pub. Health Bull. 198.

Roetman, E. T.
1944. Viscose-rayon manufacturing wastes and their treatment. Water Works and Sewerage, July and August 1944.

Surber, E. W.
1937. Rainbow trout and bottom fauna production in one mile of stream. Trans. Am. Fish. Soc. 66 (1936): 193-202.

1939. A comparison of four eastern smallmouth bass streams. Trans. Am. Fish. Soc. 68 (1938): 322-335.

1942. A quantitative study of the food of the smallmouth black bass (Micropterus dolomieu) in three eastern streams. Trans. Am. Fish. Soc. 70 (1940): 311-334.

Wiebe, A.H.
1928. Biological survey of the upper Mississippi River with special reference to pollution. Bull. U.S. Bur. Fish. 43 (1927) pt. 2: 137-167. (Doc. 1028).

West Virginia Water Commission.
1948. Potomac basin zoning report, July 1, 1948. West Virginia Water Commission, Charleston, W. Va., 40 pp.

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AQUATIC ORGANISMS AS AN AID IN SOLVING WASTE DISPOSAL PROBLEMS*

By Ruth Patrick

Curator, Dept. of Limnology, Academy of Natural Sciences of Philadelphia, Philadelphia, Pa.

This paper discusses the various ways in which aquatic organisms may be of use in solving problems associated with waste disposal. Since many state and federal laws set forth that nothing may be discharged that is deleterious to aquatic life, the most expedient way to determine the effect of an effluent is to study the aquatic organisms themselves.

In every river that has not been adversely affected by pollution there is a great variety of aquatic life. These organisms do not represent a great mass of living things, but rather they are organized into an intricately balanced system, often referred to as a food chain of biodynamic cycles.

Bases of Food Chain

At the base of the food chain are the bacteria. These organisms use the complex wastes entering a river as a source of energy in their metabolism. In so doing they break down the wastes into substances that can be used as a source of food by other organisms. These processes, which are often referred to as decay or decomposition, occur most rapidly when the bacterial population is of optimum size. When the bacteria become too numerous the processes are slowed down. The protozoa and other small invertebrates which feed on bacteria are instrumental in keeping the bacterial populations in check.

The algae are also at the base of the food chain. They are able to utilize inorganic substances to make proteins and carbohydrates, which are used as a source of food by other organisms. Indeed algae have often been referred to as the grasses of the sea. Upon them not only the many different invertebrates, but also some fish and other vertebrates, feed directly. Besides their value as a source of food they also replenish the oxygen supply of a river by a process known as photosynthesis. This is the method by which carbohydrates are synthesized and oxygen is given off as a by-product. Indeed, in many rivers this is the principal way in which oxygen is restored after it has been depleted.

The algae and the bacteria are the most important organisms in bringing about the "rejuvenation" or "cleansing" of a river. The roll of the fungi is also significant in this respect, but as yet not as well understood.

Many Food Chains Involved

As previously stated, many invertebrates, such as the worms, the snails, and the insects, feed directly on the bacteria, the fungi, and the algae. They in turn are a source of food for the carnivorous species; thus, a closely integrated food chain is formed.

This food chain does not consist, however, of a single series of links, but rather of a series of chains that are sometimes interlinked. Thus, pollution may break one series of links, yet not completely destroy the chain. It is only when pollution is extreme that the chain is completely broken and the higher forms of life are completely eliminated. Thus, when one is concerned with the problems of waste disposal and river conservation, he must concern himself with the whole pattern of life in the river rather than just one group; for example, the fish.

Pollution Effects

There are commonly five ways in which wastes may harm the aquatic life of a river, as follows:

1. They may produce oxygen deficiency. This may be due to the bacteria, which attack the wastes and use oxygen in their metabolic processes. The wastes also may not be completely oxidized when they are discharged and thus take up oxygen from the water in completing the oxidation necessary to stabilize them.
2. They may be toxic to aquatic life. This may be due to the nature of the chemicals themselves. However, it may be due to the pH which they create in the river. Wastes also may be toxic due to the osmotic pressure which they develop in river water, thus bringing about conditions unfavorable for aquatic life.
3. Temperature changes produced by wastes may be harmful in two ways. The amount of change which they produce may be deleterious. It is a well known fact that a sudden change in temperature of more than two degrees is harmful to the sunfish. Also, a waste, by raising or lowering the temperature of a river only two degrees, may cause the temperature of the water to be in a critical range deleterious to the functioning of certain physiological processes necessary for life.
4. The physical properties of the wastes may be harmful. They may carry suspended solids that are abrasive and thus injure mechanically the membrane of the gills of fish. In other cases, such as oil, they may coat the gill structures and thus make the absorption of oxygen from the water impossible.
5. Wastes may render the habitats of aquatic organisms untenable. For instance, suspended solids may settle out and clog up the natural habitats of aquatic organisms. Eggs may become buried. In other

*Presented at 25th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; NewYork, N.Y.; Oct. 6-9, 1952 cases the added pressure created by settleable solids may cause the egg cases to burst. Some wastes produce turbidity, thus hindering light penetration. Thus, the photosynthetic zone of a river will be greatly restricted and the algal production limited.

Besides bringing about death of organisms, waste may lower their resistance to the normal factors in the environment so that eventually the population dies out. To date these effects of wastes have been studied very little.

The Academy of Natural Sciences of Philadelphia has used two approaches to study the effect of pollution on a river - laboratory tests and river surveys.

Laboratory Tests

For determining the oxygen consumption of a waste, a combination of tests are used: immediate oxygen demand, biochemical oxygen demand, and complete oxygen demand. These tests are well described in the literature.

The methods for determining the toxic effects of wastes on aquatic life have, to a great extent, been developed in the Academy laboratory. A considerable part of this work was done with the aid of a grant from the American Petroleum Institute.

Realizing the importance of the bio-dynamic cycle, the effect of a given waste is determined by using organisms representing three stages in the cycle. These organisms are as follows:

1. An alga that is important as a producer of oxygen, and as an organism that can convert inorganic substances into a direct source of food for many aquatic animals.
2. An invertebrate that serves as a direct food for fish. As representatives of this group, insects and snails have been used.
3. Fish, because of their recreational and economic importance.

The fish tests are conducted according to the methodology set forth by the Federation's Subcommittee on Toxicity (1).

Insect and Snail Tests

The insect and snail tests have been patterned after the fish tests. As with the fish, care is taken to assure that the organisms are thoroughly acclimated to laboratory conditions. This is determined by a very low death rate and by the fact that growth is taking place in the acclimatization tank over a period of time. This takes several weeks, and sometimes months, to ascertain. The invertebrate tests are conducted under constant temperature and dissolved oxygen conditions. A constant volume of fluid to organism is maintained. The organisms are not fed during the test. As in fish, death is a difficult condition to establish. It is defined as lack of response to tactile stimulus and failure to recover. This is accompanied by various changes in the appearance of the organisms. In insects the same procedures as those used with fish are followed. In the case of snails, after they fail to respond to tactile stimuli, they are placed in uncontaminated water in which they have been reared. If they do not recover in 48 hr., they are determined to be dead.

Algae Tests

The algae test, although similar fundamentally, are quite different from the fish or insect tests. For these tests the diatom Nitzschia linearis was chosen. This diatom is commonly found in eutrophic streams and rivers which have not been adversely affected by pollution in the eastern and midwestern sections of the United States. The tests are conducted in Erlenmeyer flasks. The light source is artificial, being a combination of neon and "daylight" fluorescent lights. The tests are usually conducted at 18° to 20° C., depending on the temperature of the water into which the waste being tested will be discharged. The dilution water, as in the case of the fish, is a natural water or a synthetic water, which has been selected because it matches in chemical composition the water of the river into which the waste will be discharged.

The diatom cultures used in these tests consist of a single species of algae. They are cultured in the laboratory several months before testing, and are known to be maintaining a division rate characteristic of healthy diatoms of this species. Since death is a difficult thing to determine in a diatom, the point at which the growth rate is decreased 50 per cent below that of the control is taken as comparable with the median tolerance limit obtained in fish tests.

In the course of experimentation it has been found that the rate of growth is influenced by the size of the inoculum. Therefore, it is necessary that the same size inoculum be used in the control as in the tests. This is verified by counting the number of cells per milliliter in each flask at the beginning of the experiment. All tests, as well as the control, are run in duplicate. All subsequent counts are made in the same manner as at the beginning of the test to determine the rate of growth.

The duration of the test should be from 5 to 7 days. Often, at the beginning of an experiment, there is a "lag" effect before the diatoms respond to the test medium. This effect may last for 48 hr. From the third to the seventh day is the time when the growth rate can be most accurately correlated with the effects of the test medium. After this length of time some of the necessary nutrients in the dilution water may be used up and the effect produced may be due to malnutrition rather than to toxicity.

The tests described are acute toxicity tests. It is hoped that chronic toxicity tests may be developed in the near future. This would help to determine whether a substance would lower the resistance of an organism so that it could not successfully compete in nature.

Value of Laboratory Toxicity Tests

The tests described would be of value to industry in solving the following types of problems.

1. In the planning of waste disposal, (a) to determine just how much of each type of waste can be safely discharged into a river and (b) to separate the unharmful from the toxic wastes and thus reduce the cost of waste treatment.

2. In changing a process, to determine whether a new process will produce a more severe waste problem.

3. In installing new types of waste treatment, to determine whether the effluent from such a treatment is as harmless as the specifications state.

4. When dumping settling basins at high river flow, to determine how much can be dumped at a given flow without damaging the aquatic life.

5. When an industry is accused of causing a given damage and there are many other effluents emptying into the river, to determine whether or not the accused industry is to blame.

River Surveys

The second approach to solving waste effluent problems is the biological survey of the river. As every aquatic biologist knows, the ecology of the river is a very complex result of many interacting factors. Because of this, no series of toxicity tests can accurately determine the effect of a waste in a river. They merely provide an approximation of what will happen. The only way to know the effect of a waste on a river is to study the river itself.

The methodology for conducting a biological survey was published in the Proceedings of the Academy of Natural Sciences of Philadelphia in 1949. In a river survey, all of the organisms established in a given region of the river are identified as to species. The chemical characteristics of the water are determined. A total bacterial count and a coliform count are made, and the B.O.D.'s are determined.

A histogram is made of each region studied. The heights of the columns are determined by the number of species of each group of organisms living in that part of the river. Since the various groups vary greatly as to the number of species in them, the height of a given column is expressed as a percentage of the number of species of that group found in a river not adversely affected by pollution. By this method the various columns are comparable.

From the pattern developed by the columns of a histogram, the state of "health" of a river is determined. Research makes it evident that the pattern of life based on all groups of organisms is a more reliable criterion for judging the "health" of a river than a single group of "indicator organisms." Just as in other scientific work, the more different evidence available to support conclusions, the more valid they usually are.

Value of River Surveys

One of the great values of this type of study is that it tells the condition in the river over a period of time. Because these aquatic organisms have life histories of varying lengths, one is able by examining the structure of the population to determine when in the past a deleterious effect occurred. This effect can be picked up over a period of a year and sometimes longer. It depends, of course, on the kind and duration of the pollution.

This type of river study may be of use to the industrialist in the following ways:

1. Such a survey before an industry starts to operate will define the condition of the river at that time. There are few large rivers in the eastern part of the United States which have not to some degree been adversely affected by pollution. It is well for the state authorities, as well as the industry, to know what the condition of the river is before the industry starts to operate.

2. This method is useful in determining whether a waste treatment program is sufficient to protect the river, or if more treatment is needed.

3. If an industry is accused of damaging a river, such a survey, comparing various sections of a river, can tell if the complaint is justified.

Such a survey is certainly the most direct approach to use in determining the condition of the river. It is believed that by the previously described toxicity tests and biological surveys definite methods have been developed which should be of great aid to industries and to states in defining their pollution problems.

Reference

1. Doudoroff, P., et al., "Bio-Assay Methods for the Evaluation of Acute Toxicity of Industrial Wastes to Fish". THIS JOURNAL, 23, 11, 1380 (Nov., 1951).

DISCUSSION

By Arden R. Gaufin and Clarence M. Tarzwell

Limnologist and Chief, Biology Section, respectively, USPHS Environmental Health Center, Cincinnati, Ohio

Cleaning up the rivers, lakes, and bays of the country will require a great deal of money and the cooperative effort of many different groups of people. To accomplish this task and properly control the disposal of industrial and municipal wastes into surface waters, the pollutional nature of these wastes and their influence on aquatic life must be considered.

The value of fishery resources and the magnitude of the economic loss caused by the destruction of aquatic life by the industrial and municipal pollution of waters are being more widely recognized. Many states have adopted legal measures providing for the protection of fish and other aquatic life from pollution. While some have interpreted this legislation as applying only to the acute poisoning or killing of fish, Dr. Patrick's group has dealt with the fish food organisms, as well as the fish, and also has given consideration to the chronic effects of wastes on aquatic life.

In studying the effect of pollution on a river, the best type of biological program is that which recognizes the complexity of the ecological factors involved. In combining laboratory tests with river surveys, the author is attempting to gather as many different types of evidence as possible before drawing any conclusions. She is to be commended for using an approach which is more thorough than that normally used in the past for examination of this complex problem.

The need for experimental studies dealing with the toxicity of pollutants to aquatic life is great. Dr. Patrick has already discussed some of the methods and the importance of conducting such toxicity tests. Fish bio-assay procedures for most industrial wastes are not costly and are not especially difficult to perform. On the basis of toxicity determinations, it is usually possible to predict whether a waste can be discharged at a given rate without causing direct injury to fish in the receiving water. Such data also are helpful in determining the amount of treatment required, the portion of the waste requiring treatment and the effectiveness of treatment methods (1).

It has been mentioned by Dr. Patrick that another use of this method is to determine whether the discharges of a given industry are responsible for causing damage when there are many effluents emptying into the river. In such a case the character of the receiving stream is of considerable importance in determining the toxicity of a waste. Further, the toxicity of wastes can be greatly influenced by interactions between their individual components and the dissolved minerals present in widely varying amounts in receiving waters. For instance, the salts of heavy metals are generally more toxic in soft or acid waters than they are in alkaline water. Synergy and antagonism must be considered. For example, mixed solutions of cupric and zinc salts have been found to be much more toxic to minnows, than either metallic salt alone (2).

Dr. Patrick's method for conducting a biological survey of a river is to be commended for the completeness of its scope and for attempting to formulate criteria which might be useful in evaluating the effects of pollution on streams. However, for many purposes it should not be necessary to conduct such extensive or complicated studies as those outlined.

The concept of a healthy stream as being one with a large number and wide variety of species may serve as an index of conditions in some streams, but there are many areas in which it will not apply. For example, in many of the purest streams the variety and abundance of both fish and invertebrate life is distinctly limited. In Colorado and Utah many trout streams have a fish fauna of as few as 3 to 5 species and the variety and abundance of bottom fauna depends largely on the geological nature of the drainage basin (3) (4). The water in these streams is clear, sparkling, and usually meets drinking-water standards. These streams are not biologically abnormal or polluted from any standpoint.

Although heavy pollution drastically reduces the number and variety of species in a stream, limited organic pollution may fertilize a stream and increase production. There is also a great increase in the varieties of aquatic life following recovery in streams polluted with many organic wastes. Many polluted streams have a greater number of fish species than do the purest streams. Indices of stream conditions developed in a local area should be applied only in those areas having similar ecological characteristics.

In stream sanitation work it is not essential that the biodynamic cycle be preserved in its primitive condition. Such conditions have already been largely eliminated by deforestation, overgrazing, mining, and agricultural practices. The objective now is to manage waters so that they will produce the maximum sustained yield of recreation and sport and commercial fishing consistent with the capacity and other reasonable uses of the waters. Among the aquatic fresh-water organisms, fish are the most important to the general public. The destruction of a few sensitive species is of little importance if they are replaced by others equally desirable so that the fish yield is not impaired. In the final analysis the fish yield is the important measure of effective stream management and fishlife should be considered as the major index of stream conditions.

Dr. Patrick's system for making stream surveys is costly and requires the help of a considerable number of well-trained scientists for it to be usuable. Many state agencies charged with water pollution control, as well as small industries, do not have money or personnel for a biological program of the magnitude recommended.

When conducting biological investigations for the evaluation or solution of pollution problems, careful formulation of objectives is required. If the objective is to determine only general stream conditions, a reconnaissance survey is favored to determine the relative quantitative and qualitative aspects of the biota. In such a program the pollutional condition of a stream can often be determined by reference to those groups of organisms which best reflect the ecological conditions under which they live. If the objective of a stream survey is to ascertain the economic loss caused by the damaging effects of pollutants on the fishery of the stream, then it is necessary to determine the composition of the fish fauna in the stream and the changes in that fauna which might have occurred in the past. Necessary data on fish populations and yield can be obtained by creel censuses, records of commercial catches, seining, gill netting, trapping, etc. Since the procedures for conducting fishery yield surveys have been fairly well standardized by workers in fish management, it is not deemed advisable to dwell further on the subject here.

Several different approaches have been advocated by biologists in using aquatic organisms as indicators of the pollutional conditions of a stream. Dr. Patrick, emphasizing primarily a qualitative approach, maintains that the total number of species, rather than the qualitative and quantitative characteristics of the population, constitutes the most valuable index as to the health of a stream. Ellis (5) advocated a semi-quantitative approach when he stated that the relative abundance of indicator species was the important consideration. Biologists of the USPHS Environmental Health Center at Cincinnati, Ohio, have found that both criteria are important and serve best when used concurrently. For example, Gaufin and Tarzwell (6) found that in a small polluted stream near Cincinnati, the biota in the polluted zones was characterized by few species but large numbers of individuals, whereas in the clean-water zones there were many species but comparatively few individuals of each species.

Quantitative measurements of the total number of species or individual organisms in any given area of a stream are often difficult to obtain. For example, Environmental Health Center biologists took a series of nine random samples, by means of an Ekman dredge, from a pool in a small sewage polluted stream near Cincinnati. A total of 50 species of macro-invertebrates was collected. On the average, it was determined that any three of these samples would have yielded only 60 per cent of the 50 species. Seven samples would have been required to have obtained 90 per cent of the types represented.

Where personnel are not available to do all of the technical taxonomic work required for species identification, or to take enough quantitative samples to accurately determine the abundance of individual species or organisms, a practical biological inventory is still possible.

Specifically, the degree and extent of pollution in a stream can be determined accurately by reference to the macro-invertebrate fauna, particularly that found in the riffles. A biological analysis of the pollutional status of a stream can be obtained in the field through recognition of the biological orders, families, or genera in the invertebrate associations encountered. This type of biological inventory is superior to limited chemical data, as the complex of such organisms which develops in a given area is in turn indicative of present, as well as past, environmental conditions in that area. Bottom organisms are more fixed in their habitat than are fish or plankton and cannot move to more favorable surroundings when pollutional conditions are most critical.

Shortened procedures, such as that suggested, cannot be recommended for use by anyone except a well-trained aquatic biologist. When used properly, however, such techniques can be of considerable value to organizations having waste disposal problems to solve.

References

1. Doudoroff, P., "Biological Observations and Toxicity Bio-Assays in the Control of Industrial Waste Disposal." Proc. 6th Ind. Waste Conf., Purdue Univ. (1951).
2. Doudoroff, P., "Some Recent Developments in the Study of Toxic Industrial Wastes." Proc. 4th Pacific Northwest Ind. Waste Conf., Washington State College (1952).
3. Gaufin, A.R., "A Comparative Study of the Bottom Fauna Productivity of the North and South Forks of the Provo River at Stewart's Ranch, Utah." Midwest Wildlife Conf., University of Wisconsin (In manuscript form) (1949).
4. Pennak, R.W., and Van Gerpen, E.D., "Bottom Fauna Production and Physical Nature of the Substrate in a Northern Colorado Trout Stream." Ecology 28, 1 (1947).
5. Ellis, M.M., "Detection and Measurement of Stream Pollution." U.S. Bureau of Fisheries, Bull. 22 (1937).
6. Gaufin, A.R., and Tarzwell, C. M., "Aquatic Invertebrates as Indicators of Stream Pollution." Pub. Health Rep., 67, 57 (1952).

DISCUSSION

By Ruth Patrick

As Dr. Gaufin has pointed out, there may be a synergistic effect between an effluent entering a river and substances already in a river. For this reason toxicity tests may be used as a yardstick, but one must study the river itself to determine accurately the effect of an effluent.

It is true that there are many different types of rivers in the country, with varying amounts of aquatic life. However, the writer has yet to find a river with two ecologically similar areas; one adversely affected by pollution with industrial or municipal wastes, and one unpolluted in which the unpolluted area did not have a greater diversity of species of diatoms, insects, and fish than the polluted area.

It is correct that a well-qualified biologist can determine that a river is badly polluted without determining all the species. But if it is desired to determine trends of conditions or have definite evidence for future comparison, the species present must be determined.

Very rarely are all the species of a genus indicators of pollution. For this reason, it would be very dangerous to draw positive conclusions from determination only to genus.

Dr. Gaufin indicated that the method described is a qualitative one. It is qualitative in that the kinds of species composing the biodynamic cycle are considered. It is, however, quantitative in that the measure also considers the number of species. No one has yet devised a statistically valid quantitative method for benthic forms in a river based upon the number of individuals.

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EFFECTS OF SILTATION, RESULTING FROM IMPROPER LOGGING, ON THE BOTTOM FAUNA OF A SMALL TROUT STREAM IN THE SOUTHERN APPALACHIANS

L. B. Tebo, Jr.
North Carolina Wildlife Resources Commission
Hoffman, North Carolina

SILTATION, RESULTING FROM IMPROPER LAND - USE PRACTICES, is regarded as one of the most important factors contributing to a reduction in the acreage of desirable fishing waters in the United States. Although much information of a general nature has been published, there is a lack of quantitative data regarding the effects of siltation on stream values.

One phase of a Dingell-Johnson project, established by the North Caroline Wildlife Resources Commission during the summer of 1952, was to obtain quantitative data regarding the effect of siltation on trout streams in the southern Appalachians. The project was begun on the Coweeta Experimental Forest, located in Macon County, North Carolina, where for 20 years the U. S. Forest Service has been collecting extensive data regarding the effects of various land-use practices on experimental watersheds. The purpose of this report is to present data regarding the effects of siltation on the bottom organisms of Shope Creek, a small trout stream which received the drainage from a 212-acre logged watershed (figure 1).

During 1942, logging was commenced on the 212-acre watershed on the Coweeta Experimental Forest. The periods of activity on the watershed were:

May 1942 - Mar. 1943: Active logging
Mar. 1943 - Jan. 1945: No logging
Jan. 1945 - Nov. 1948: Active logging
Nov. 1948 - Apr. 1953: No logging
Apr. 1953 - Present: Active logging

The logging was carried out by local contractors, with no limitation of methods or supervision by the Forest Service. Logs were ground-skidded by teams. Because of steep slopes, the roads and skid trails were built parallel and adjacent to the channel of the drainage stream. The roads were characterized by excessively steep grades alternating with level stretches. No surfacing material and no drains or water cutoffs were used on the roads. With the termination of the original logging in 1948, 2.2 miles of road had been constructed on the 212-acre watershed.

Presented at the Eighth Annual Conference of the Southeastern Association of Game and Fish Commissioners, New Orleans, Louisiana, November 1-3, 1954, to report on one phase of a Dingell-Johnson project undertaken by the U.S. Fish and Wildlife Service, U.S. Forest Service, and North Carolina Wildlife Resources Commission.

Description of Shope Creek

Shope Creek, which received the stream from the logged watershed, flows into Coweeta Creek and thence to the Little Tennessee River. Shope Creek drains a watershed of approximately 1,880 acres and is typical of many smaller trout streams in the southern Appalachians. Average monthly streamflow for a 6-year period ranged from a low of 2.31 c.f.s. during October to 8.32 c.f.s. during February (figure 2). Figure 3 illustrates the frequent occurrence and magnitude of floods occurring in this small trout stream.

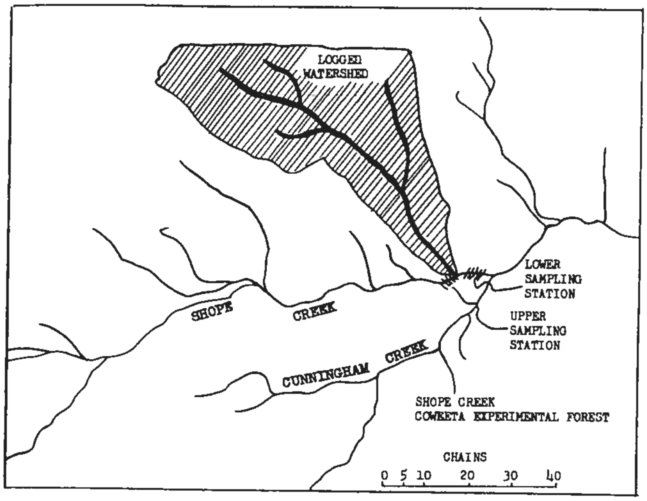
During the period of this study, stream temperatures have ranged from a low of 33.0°F. during December 1952 to a high of 65.5°F. during August 1953. During the fall of 1953, the water had a pH of 6.6 and a methyl orange alkalinity of 8.0 p.p.m.

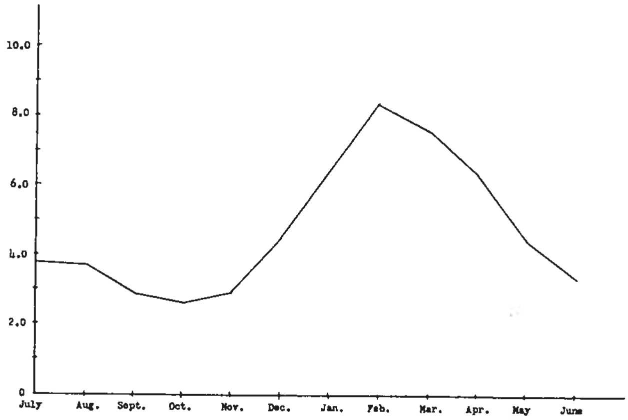
The upper portion of the stream is characterized by steep gradient (900 feet to the mile) with series of cascades and low waterfalls, interspersed with large pools having excellent shelter in the form of large boulders and broken water surface. The bottom is predominantly boulders and rubble with occasional outcrops of granite bedrock. From approximately one-fourth mile above the sampling stations to the lower boundary of the experimental forest, there is a noticeable change in the habitat. The gradient is 224 feet per mile, and the cascades and waterfalls of the upper section are replaced with short riffles and shallow pools. There is no rooted aquatic vegetation in the stream.

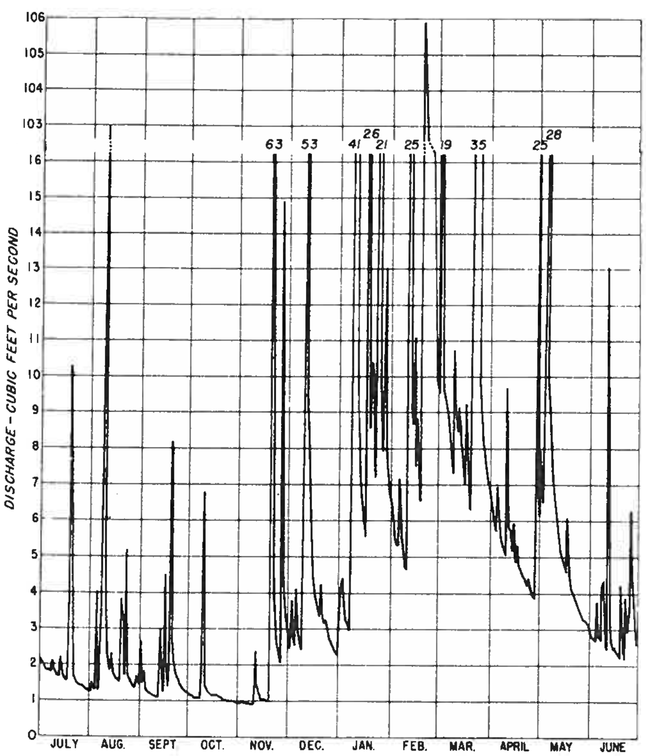
As nearly as can be determined, no trout have been stocked in Shope Creek since 1930, when rainbow trout were introduced by local residents. At present, the upper and lower reaches of the stream contain brook and rainbow trout, respectively, with an intermingling of these two species in the section just above the mouth of the stream from the logged watershed. No fishing has been permitted for the past 4 or 5 years. However, prior to closure, the stream had an excellent reputation among local fishermen.

Water Quality

During storm periods, the effect of the stream from the logged watershed (Watershed No. 10) on Shope Creek is illustrated by the turbidity of water samples collected at the mouth of the stream from No. 10, from Shope Creek above the mouth of No. 10, and from Shope Creek below the mouth of No. 10.







Date	Turbidity (p.p.m.) Stream from Number 10	Shope Creek Above 10	Shope Creek Below 10
Apr. 11, 1947 ---	1,200	25	390
Feb. 20, 1954 ---	1,371	67	261

The roads and skid trails proved to be the major source of turbidity (Lieberman and Hoover 1948). Skidding logs down the steep slopes creates channels which concentrate runoff, resulting in a high rate of erosion. For the 2-year period from April 1951 to March 1953, an average of 5.34 cubic feet of soil per lineal foot of road surface were eroded from the logging road. This would amount to a loss of 2,297 cubic yards of soil for the total 2.2 miles of road system.

During periods of low streamflow, the physical effects of siltation on Shope Creek are noticeably evident. During the low flows of late summer and fall, the bottom of Shope Creek above the mouth of the logged watershed accumulates a thin layer of finely divided organic matter, while below the mouth of the logged watershed the stream bottom in both pools and riffles is covered with a layer of sterile sand and micaceous material which may accumulate to a measured depth of 10 inches.

Bottom Fauna

Because of its relative stability in location, the bottom fauna was selected to obtain a measure of the effects of siltation on the stream community. The limited section of Shope Creek affected by siltation from the logged watershed made a direct evaluation of the fish population impractical. The small stream from the logged watershed is too small to support a resident trout population.

Within limits of space and reproductive capacity, the available food in a stream can certainly be regarded as a factor limiting the production of trout. Leonard (1948) and Henry (1949) have stated that in Michigan trout waters the food supply often is the most important limiting factor in trout production. Allen (1951), working on New Zealand streams, found that the bottom fauna was a limiting factor in the production of brown trout. Tarzwell (1938b) found an apparent relation between the quantities of stream foods present and trout production in streams in the southwestern United States.

(Top to Bottom)

FIGURE 1. -- Map of Shope Creek, Coweeta Experimental Forest, showing the location of logged area and sampling stations.

FIGURE 2. -- Mean monthly streamflow (c.f.s.) of Shope Creek for the 6-year period, 1937-42.

FIGURE 3. -- Peak daily streamflow (c.f.s.) of Shope Creek for the period, July 1952 to June 1953.

(Drawings courtesy of the author)

In trout streams of western North Carolina the food of trout is obtained from three sources: the bottom fauna, terrestrial insects, and fish. Analysis of 241 rainbow trout stomachs collected from streams of western North Carolina during 1952 and 1953 indicate that, from January to June, 83 percent of the diet is obtained from the bottom fauna. From June to December, 42 percent of the food of rainbow trout is obtained from the bottom fauna. Terrestrial insects are of major importance during the summer and fall months. Of the 241 trout stomachs examined, only 1 specimen contained fish remains and 3 had eaten salamanders.

From October 1952 to June 1953, 108 square-foot bottom samples were collected at monthly intervals from Shope Creek immediately above and below the mouth of the stream draining the logged watershed. The standing crop of bottom organisms was at all times very low, with a high average of 49.0 organisms per square foot occurring at the untreated station on November 13 (table 1). The highest average volume occurred in the samples of January 14 at the untreated station. The high volume occurring on January 14 resulted from an abundance of large cranefly larvae, *Tipula* sp., and the stonefly nymph, *Pteronarcys scotti*. The frequent occurrence of floods (figure 3) is undoubtedly an important factor contributing to the low quantities of bottom fauna produced in this small trout stream.

From October 1952 to February 1953, the upper station had a significantly larger numerical standing crop of bottom organisms than did the lower station, which was subjected to the siltation from the logged watershed (tables 2 and 3). The volume of bottom organisms was greater in the control section on all but two sampling dates, April 23 and May 21, 1953 (table 1).

A major flood that occurred on February 21, 1953, increased the flow in Shope Creek from 6.7 c.f.s. to 105.8 c.f.s. in a 24-hour period (figure 3). The flood completely resorted bottom materials and flushed the deposited sediments downstream, exposing the original rubble and gravel bottom. On February 26, 1953, the numbers of bottom organisms at the lower station had been reduced 73.2 percent, as compared with the January level, while the numbers at the untreated station had been reduced 22.2 percent (table 1).

High water levels plus frequent rains February to May (figure 3) prevented a reaccumulation of silt in the lower section of Shope Creek. On April 2, April 23, and May 21, that section of stream produced slightly greater standing crops of bottom organisms than did the control section. The difference was not significant ($F = 0.208$ d.f. $= 1$ and 30), and was the result of an increase in the numbers of mayfly nymphs in the treated section of stream (table 1). The inexplicable superiority of mayflies in the treated section of stream may have been the result of reduced competition and improvement in habitat, both caused by the February flood.

When samples were collected in June 1953, silt and sand again had begun to accumulate in the treated section of the stream, and the control section again produced a greater average standing crop of bottom organisms (table 1). The difference was not statistically significant ($t = 1.42$ d.f. $= 10$).

Before the reduction in the quantity of stream bottom organisms, from October through February, can be attributed to the effects of siltation, it is necessary to assume that there was no difference between the two sampled stations prior to logging. The study was commenced quite some time after logging took place, and it is therefore impossible to test this basic assumption. However, the fact that the sampled areas are on immediately adjacent and similar sections of the same stream, as well as the comparable quantities of bottom fauna produced during the spring months, when silt did not accumulate in the treated section of the stream, lends support to the assumption that there were no pretreatment differences between the two stations sampled.

With the exception of the difference in mayflies during the spring months, as noted above, there were no appreciable qualitative differences between the two stations sampled (table 1).

Discussion

The period during which the standing crop of organisms in the treated section of Shope Creek was significantly lower than in the control section coincided with the period of maximum accumulation of inorganic silt and sand. Inorganic silt and sand have poor ability to support a fauna. Tarzwell (1938a) found that mineral silt bottoms were poor in food. Murray (1938) stated that, in Indiana streams, sand by itself is likely to be barren of life.

In addition to its poor ability to support a fauna, the shifting sand created an unstable habitat, and organisms inhabiting it were particularly vulnerable to decimation by flood waters. The flood during February removed the accumulated sediments and resulted in a drastic reduction in the number and volume of bottom organisms in the treated section of stream. During the high flows and frequent rains from February to May, the rate of dilution by clear water from the main fork of Shope Creek prevented the reaccumulation of sediment in the treated section of stream. A fauna which resulted was quantitatively comparable to that found in the control section. It is doubtful that the rapid recovery after the flood -- undoubtedly by means of the drift of organisms from the control section -- could occur if all of the Shope Creek watershed were subject to the effects of siltation.

The low fertility and frequent occurrence of floods in western North Carolina trout streams results in a low production of stream bottom organisms under the very best conditions. Therefore, because of the dependence of trout on stream-produced organisms, any outside factor, such as siltation, which reduces the normally low quantities of stream organisms will ultimately have a deleterious effect on the trout population.

It is apparent from the Coweeta studies that poorly planned road systems and the promiscuous úse of smaller stream channels as skid trails result in a

TABLE 1.--Numbers and volume of bottom organisms collected from riffles in Shope Creek from October 1952 to June 1953 at stations above and below the mouth of a tributary stream draining a logged watershed

	October 16		November 13		December 17		January 14		February 26	
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Number of samples	3	3	3	3	6	6	6	6	6	6
Total number of organisms	116	74	147	78	226	137	234	164	182	44
Number per square foot	38.7	24.7	49.0	26.0	37.5	22.8	39.0	27.3	30.3	7.3
Standard deviation	9.29	13.0	12.1	14.7	13.6	6.80	15.4	16.9	22.3	3.19
Total volume (cc)[1]	0.70	0.15	0.70	0.20	3.20	0.50	5.70	2.40	2.65	trace
Volume per square foot	0.23	0.05	0.23	0.07	0.53	0.08	0.95	0.40	0.44	trace
Diptera	27	4	57	33	65	55	90	70	76	13
Trichoptera	18	12	7	5	25	20	19	9	10	4
Plecoptera	25	9	49	-----	57	24	50	18	9	6
Ephemeroptera	30	23	22	29	53	23	54	51	36	16
Odonata	1	-----	-----	-----	2	-----	2	1	1	-----
Coleoptera	11	25	12	11	23	15	19	15	21	5
Oligochaeta	4	1	-----	-----	-----	-----	-----	-----	-----	-----

	April 2		April 23		May 21		June 12	
	Above	Below	Above	Below	Above	Below	Above	Below
Number of samples	6	6	6	6	6	6	6	6
Total number of organisms	259	283	239	249	180	196	256	202
Number per square foot	43.2	47.2	39.8	41.5	30.0	32.7	42.7	33.7
Standard deviation	17.6	17.6	19.3	26.6	9.27	15.2	11.3	10.7
Total volume (cc)[1]	5.20	3.75	2.50	2.70	1.35	2.60	3.80	1.20
Volume per square foot	0.87	0.63	0.42	0.45	0.23	0.43	0.63	0.20
Diptera	41	33	32	24	25	16	9	10
Trichoptera	13	11	8	5	4	11	18	16
Plecoptera	41	29	24	20	17	31	75	21
Ephemeroptera	148	190	160	189	106	130	112	127
Odonata	-----	1	-----	-----	-----	-----	2	-----
Coleoptera	15	17	12	10	25	5	29	24
Oligochaeta	-----	-----	1	1	2	2	4	1
Crayfish	1	1	1	-----	1	1	3	1
Salamanders	-----	1	-----	-----	-----	-----	-----	-----

[1] Does not include salamanders and crayfish.

TABLE 2.--Analysis of variance on the basis of total numbers of organisms in October and November 1952

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between stations--------	1	1,027	1,027	1/6.62
Between months----------	1	102	102	------
Interaction-------------	1	62	62	------
Error-------------------	8	1,239	155	------

1/ Significant at 5-percent level.

TABLE 3.--Analysis of variance on the basis of total numbers of organisms in December 1952 and January and February 1953

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between stations--------	1	2,434	2,434	1/15.02
Between months----------	2	1,372	686	4.23
Interaction-------------	2	207	104	------
Error-------------------	29	4,706	162	------

1/ Significant at 1-percent level.

high rate of erosion and consequent siltation of the stream channel. Steep grades, lack of allowance for proper drainage, and the proximity of roads to stream channels are particularly conducive to siltation. Also, it is the opinion of many foresters that properly constructed roads, in addition to conserving water values, will, in the long run, pay the logging operator by reducing road maintenance work. Where important fishery values are involved, it is imperative that skid trails and road systems be carefully located and constructed.

Summary

1. From 1942 to 1948, a 212-acre watershed on the Coweeta Experimental Forest, Macon County, North Carolina, was logged by a local contractor. Roads and skid trails were built parallel and adjacent to the stream channel. No surfacing material and no drains were used.

2. The physical and chemical characteristics of Shope Creek, a small trout stream which receives the stream from the logged watershed, are described.

3. During storm periods the turbidity of Shope Creek was appreciably increased by the highly turbid waters from the logged area. The accumulation of sand and silt in Shope Creek below the mouth of the stream from the logged watershed is described.

4. Roads and skid trails proved to be the major source of turbidity. From April 1951 to March 1953, an average of 5.34 cubic feet of soil per lineal foot of road surface was eroded from the logging road.

5. From October 1952 to June 1953, 108 square-foot bottom samples were collected at monthly intervals in Shope Creek at stations above and below the mouth of the stream from the logged watershed.

6. From October 1952 through January 1953, the period of maximum accumulation of sediment in the affected section of Shope Creek, there was a significantly lower standing crop of bottom organisms at the station below the mouth of the logged watershed.

7. A flood on February 21, 1953, removed the accumulation of sand and silt in Shope Creek below the mouth of the logged watershed and reduced the bottom fauna at the lower station to 7.3 organisms per square foot, as compared with 25.5 organisms per square foot at the upper station, which had not been subject to siltation from the logged watershed.

8. The February flood exposed an excellent bottom of rubble and gravel at the lower station; from February through May spring rains and high streamflow prevented the reaccumulation of sand and silt at the lower station on Shope Creek. During this period there was no significant difference in the standing crop of bottom fauna at the control and treated stations. During June, when silt had begun to reaccumulate, the control section again produced a larger standing crop of bottom organisms. The difference was not statistically significant.

Acknowledgments

Facilities of the U.S. Forest Service station at Coweeta Hydrologic Laboratory have been utilized freely in the conduct of this study. The cooperation and advice of Mr. E.A. Johnson and Dr. T. C. Nelson, technicians at Coweeta, have been particularly helpful.

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Literature Cited

Allen, K. R.
1951. The Horokiwi stream: A study of a trout population. New Zealand Mar. Dept., Fish Bull. 10, 231 pp., illus.

Henry, K. W.
1949. Michigan trout waters. Mich. Forester 30: 13-15, 41.

Leonard, J. W.
1948. Importance of fish food insects in trout management. Mich. Cons. 17 (1): 8-9.

Liberman, J. A. and M. D. Hoover.
1948. The effect of uncontrolled logging on stream turbidity. Water and Sewage Works 95 (7): 255-258.

Murray, M. J.
1938 An ecological study of the invertebrate fauna of some northern Indiana streams Invest. Ind. Lakes and Streams 4 (8): 101-110.

Tarzwell, C. M.
1938a. Factors influencing fish food and fish production in southwestern streams. Trans. Am. Fish. Soc. 67 (1937): 246-255.

1938b. An evaluation of the methods and results of stream improvement in the Southwest. Trans. N. Am. Wildl. Cong. 3: 339-364.

Reproduced from PUBLIC WORKS, 90 (1959): 104-110

STREAM LIFE AND THE POLLUTION ENVIRONMENT*

Alfred F. Bartsch
and
William Marcus Ingram

Increased field investigations over the past 10 years, directed toward the abatement of pollution, have prompted this pictorial presentation to show the impact of pollution upon the stream environment and in turn upon the stream life, or biota. The illustrations were developed initially for use in training sanitary engineers and supporting scientists at the U. S. Public Health Service's Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

To show schematically the effects of pollution on biota, raw domestic sewage has been chosen as the pollutant. With such a waste, the lowering of dissolved oxygen and formation of sludge deposits are the most commonly seen of the environmental alterations that damage aquatic biota. Fish and the organisms they feed on may be replaced by a dominating horde of animals such as mosquito wrigglers, bloodworms, sludge worms, rattailed maggots and leeches. Black-colored gelatinous algae may cover the sludge and, as both rot, foul odors emerge from the water and paint on nearby houses may be discolored. Such an assemblage of abnormal stream life urges communities not to condone or ignore pollution, but to abate it without delay. This biotic picture emphasizes that pollution is just as effective as drought in reducing the utility of a valuable water resource. They help to make clear that pollution abatement is a vital key to the over-all problem of augmenting and conserving waters of this land.

No two streams are ever exactly alike. In their individualism streams differ from each other in the details of response to the indignity of pollution. In the following paragraphs, and in the charts they describe, the hypothetical stream is made to conform exactly to theory, showing precisely how an idealized stream and its biota should react in a perfect system. In reality, of course, no stream will be exactly like this although the principles shown can be applied with judgment to actual problems that may be encountered.

ASSUMED CONDITIONS

The stage for discussion is set in Figure 1. The horizontal axis represents the direction and distance of flow of the stream from left to right. Time and distance of flow downstream are shown in days and also in miles. The vertical scale of quantity - or more accurately, concentration - expressed in parts per million, applies to dissolved oxygen and biochemical oxygen demand at distances upstream and downstream from the origin of the sewage discharge, which is identified as point zero. Here, raw domestic sewage from a sewered community of 40,000 people flows to the stream. The volume flow in the stream is 100 cubic feet per second, complete mixing is assumed, and the water temperature is 25°C. Under these conditions the dissolved oxygen (D.O.) sag curve reaches a low point after two and one-quarter days of flow and then

*Originally published with colored illustrations. Editorial changes have been made to make this text conform with the halftone illustrations.

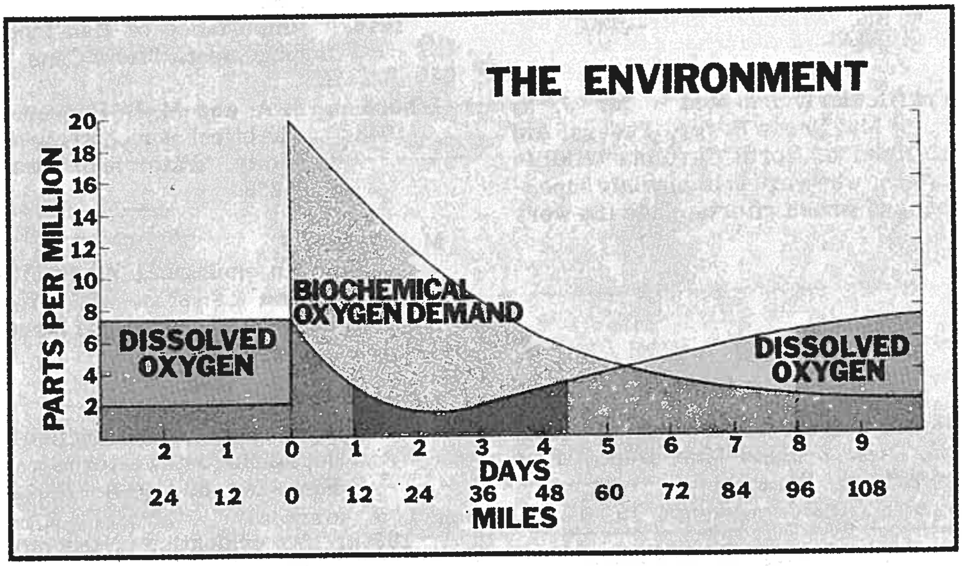

Figure 1 - The assumptions in the hypothetical pollution case under discussion are a stream flow of 100 cfs, a discharge of raw sewage from a community of 40,000 and a water temperature of 25°C, with typical variation of dissolved oxygen and BOD.

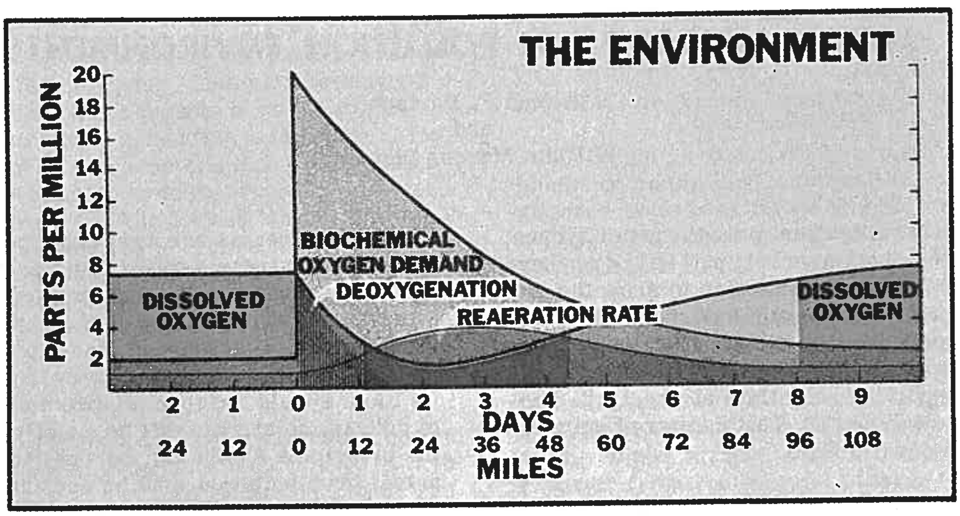

Figure 2 - The dissolved oxygen concentration in the stream is partially destroyed by the pollution load. Full depletion is avoided by reaeration processes.

rises again toward a restoration similar to that of upstream, unpolluted water.

The biochemical oxygen demand (BOD) curve is low in upstream, unpolluted water, increases at point O from the great charge of sewage and gradually decreases from this point downstream to a condition suggestive of unpolluted water. BOD and D.O. are so interrelated that the dissolved oxygen concentration is low where BOD is high, and the converse also is true. From left to right the stream zones are: clean water, degradation, active decomposition, recovery, and clean water.

EFFECTS OF REAERATION

Figure 2 represents an interpretation of the two principal antagonistic factors that have to do with the shape of the D.O. sag curve. The biochemical and other forces that tend to exhaust D.O. supplies, called collectively the process of deoxygenation, would reduce such resources to zero in about a day and one-half if there were no factors in operation that could restore oxygen to water. The river reach where D.O. would be completely gone would occur about 18 miles downstream from the point of discharge of sewage from the municipality. However, with reaeration fac-

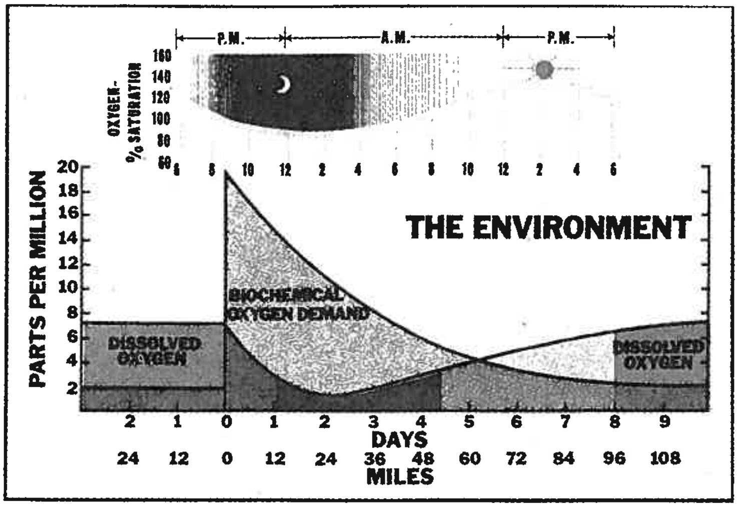

Figure 3 - Dissolved oxygen fluctuates according to available light, a result of photosynthesis. Thus, values on the lower curve are subject to daily variation.

tors at work, there is appreciable compensation for deoxygenation, and in this way the actual contour of the oxygen sag curve is determined. Thus, the low point of the curve is not attained at one and one-half days of flow at mile 18 with a zero D.O., but in reality is reached at about two and one-quarter days of flow at about mile 27. The D.O. here does not go to zero, but to 1.5 ppm.

If the population of the city remains fairly uniform throughout the year, and the flow is relatively constant, the low point of the D.O. sag curve can be expected to move up or down the stream with fluctuations in temperature. In winter, one can expect to find the low point farther downstream than shown. In other seasons, if temperatures exceed the 25°C upon which the charts are based, D.O. will be depleted more rapidly and drastically with the low point farther upstream.

The reach of any stream where the D.O. sag curve attains its low point obviously is the stream environment poorest in D.O. resources. It represents a place where aquatic life that may need a high D.O. can suffocate or from which such life may move to other stream areas where the D.O. resources are greater.

EFFECT OF LIGHT

The upper graph of Figure 3 illustrates fluctuations of dissolved oxygen that may occur over a 24-hour period at a single point in a stream with average density of aquatic greenery such as planktonic algae or larger submerged plants. For sake of explanation, any point in the recovery zone would exhibit such diurnal D.O. variations. The lower graph shows only linear changes in D.O., and gives no indication of the daily variation in availability of this vital gas that may occur at any single selected point.

If this selected point is in the recovery zone at mile 72, one can see from Figure 3 that D.O. varies from a low of about 80 percent saturation at 2:00 a.m. to about 140 percent at 2:00 p.m. Diurnal variation such as this is a result of photosynthesis chiefly in algae but in other plants also. During daylight hours these plants give off oxygen into the water in such large quantities that if the organic wastes are not sufficient to use up much of the D.O. in oxidizing sewage, the water commonly becomes supersaturated at some time during daylight hours. In addition to giving off oxygen, the photosynthetic process results in the manufacture of sugar to serve as the base from which flows the nutritional support for all stream life. The process of photosynthesis can be illustrated schematically as:

$$6\,CO_2 \quad 6\,H_2O \qquad C_6H_{12}O_6 \quad 6\,O_2$$

This action proceeds through the interaction of the green pigment, chlorophyll, contained in living plant matter, of sunlight, carbon dioxide, and even water to form the raw materials into a simple sugar and surplus oxygen.

While photosynthesis occurs, so also does respiration which proceeds 24 hours on end irrespective of illumination. In this well known process O_2 is taken in and CO_2 is given off. The algae, during daylight may yield an excess of oxygen over and above their respiratory needs, the needs of other aquatic life, and the needs for the satisfaction of any biochemical oxygen demand. Under these conditions, surplus oxygen may be lost to the atmosphere. During hours of darkness photosynthesis does not occur and gradually, the surplus D.O. that was present is used up or reduced by algae, fish, various insects, clams, snails and other aquatic life in respiration, and by bacteria in satisfaction of the BOD. That is why oxygen resources are poorest during early morning hours. During hours of darkness, a stream is typically dependent on physical reaeration for its oxygen resources after exhaustion of the "bank of dissolved oxygen," that was elevated to supersaturation levels by aquatic plants.

Obviously, on stream sanitary surveys where or-

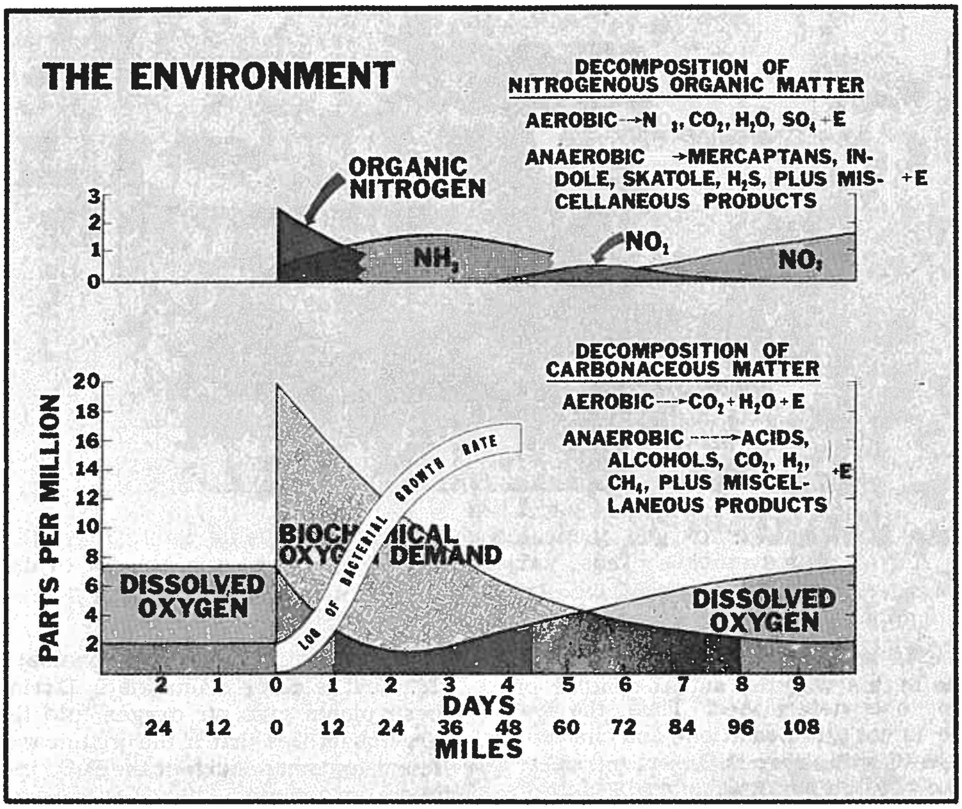

Figure 4 - With a heavy influx of nitrogen and carbon compounds from sewage, the bacterial growth rate is accelerated and dissolved oxygen is utilized for oxidation of these compounds. As this proceeds, food is "used up" and the BOD declines.

ganic wastes such as domestic sewage are pollutants, it is important to sample each station over 24 hours at intervals that are appropriate to reveal information on diurnal D.O. variations. If this is not done and station 1 is sampled consistently around 8:00 a.m. and station 6 around 5:00 p.m. over a weekly or a monthly survey, critical D.O. concentrations will not be found. If interval sampling over 24 hours cannot be done because of workday restrictions, reversing the time of sampling from the upstream to the downstream station on alternate days will at least show variations of D.O. that one can expect through an 8-hour workday.

EFFECT OF ORGANIC MATTER

The bottom graph of Figure 4 illustrates reasons for the decrease in the BOD curve progressively downstream and offers an explanation for the depression in the oxygen sag curve. On this graph there has been superimposed, in white, the shape of the log curve of bacterial growth rate. Accelerated bacterial growth rate is a response to rich food supplies in the domestic raw sewage. During rapid utilization of food, bacteria reproduction is at an optimum, and utilization of D.O. becomes fairly proportional to the rate of oxidation.

The upper graph illustrates, in principle, the progressive downstream changes in nitrogen from the organic form to the nitrate form. It demonstrates the initial high consumption of oxygen by bacteria that are feeding on proteinaceous compounds available in upstream waters in freshly discharged domestic sewage. With fewer and fewer of these compounds left in downstream waters, the BOD becomes reduced and the D.O. increases. Fat and carbohydrate foodstuffs rather than proteins could have been chosen just as well to show this phenomenon.

The nitrogen and phosphorus in sewage proteins can cause special problems in some receiving waters. Experience has shown that increasing the amount of these elements in water can create conditions especially favorable for growing green plants. In free flowing, clear, pebble brooks they appear as green velvety coatings on the stones or as lengthy streamers waving gently in the current. They are not unattractive and even, in the poetry of Nature, are complimented by the name "mermaid's tresses." These plants are not like the troublesome ones which occur mostly in more sluggish streams, impoundments or lakes, especially when they are artificially fertilized by sewage. In the clean brook, they not only are attractive and natural to see, but also they are a miniature jungle in which animals of many kinds prey upon each other with the survivors growing to become eventual fish food.

In more quiet waters, the algal nutrients in sewage are picked up for growth by less desirable kinds of algae. With great supplies of nitrogen and phosphorus made available, free-floating, minute blue-green algae increase explosively to make the water pea soup green, smelly and unattractive. In some unfortunate local-

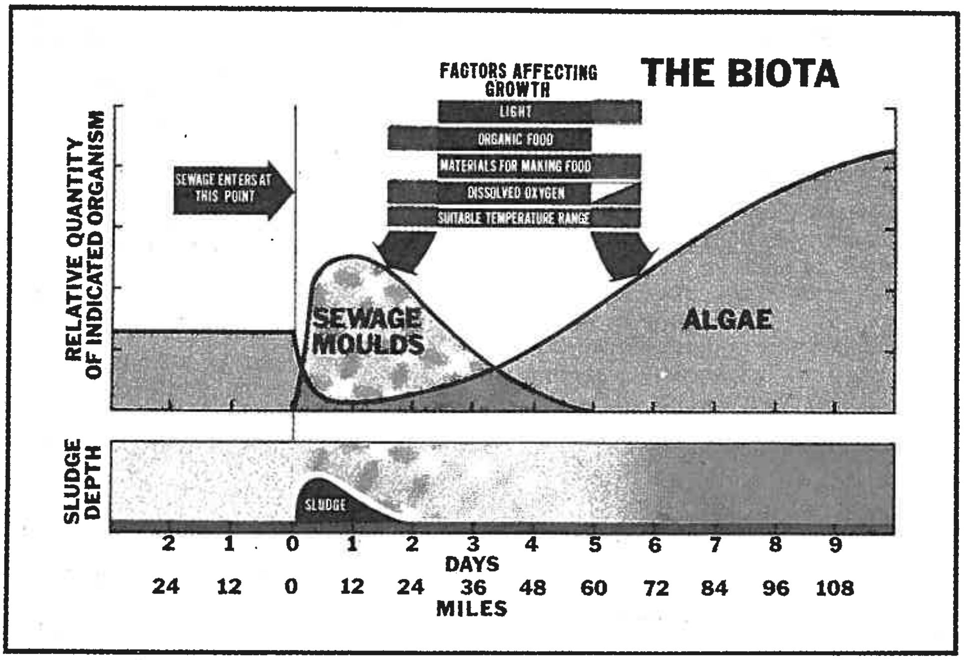

Figure 5 - Shortly after sewage discharge, the moulds attain maximum growth. These are associated with sludge deposition shown in the lower curve. The sludge is decomposed gradually; as conditions clear up, algae gain a foothold and multiply.

ities, nuisance blooms of algae have become so objectionable that waterfront dwellers have had to forsake their homes and see their property depreciate in value. The problem has been studied at a number of localities, and some studies are still in progress. Special legislation has even been formulated requiring that sewage treatment plant effluents not be discharged to susceptible lakes solely because of the algal nutrients they contain. Sometimes, under conditions not well understood, some blue-green algae develop poisons capable of killing livestock, wildlife and fish. Fortunately, such occurrences are rare. It is completely clear that sewage disposal and biological responses of even such lowly plants as algae go hand-in-hand sometimes to plague the desires of man.

AQUATIC PLANTS

In the lower part of Figure 5 a profile is shown of the water and stream bed with the vertical scale of the latter exaggerated. Sludge deposits begin to accumulate just below the point of sewage discharge. These deposits reach their maximum thickness near the point of origin but blanket the stream bed for many miles downstream. The substance of the deposits gradually is reduced by decomposition through the action of bacteria, moulds and other sludge-dwelling organisms, until it becomes insignificant about thirty miles below the municipality.

Also, at the outfall the water is turbid from fine solids held in suspension in the flowing water. Larger floating solids, destined to sink eventually to the stream bed as settleable solids, are visible on the water surface as they drift downstream. Both the fine and large solids contribute to the sludge deposit, and as they settle progressively to the bottom of the stream bed, the water becomes clear and approaches the color and transparency of upstream water above the point of sewage discharge.

The upper graph illustrates the relative distribution and quantities of algae, various moulds, and filamentous bacteria such as Sphaerotilus. From mile 0 to mile 36, high turbidity from floating debris and suspended solids is not conducive to algal production. Thus, except for slimy blue-green marginal and bottom types, algae are sparse in this reach. In order to grow well algae need sunlight, and here it cannot penetrate the water effectively. Also, floating solids that settle out of the water carry to the bottom with them floating algae that drift into the polluted zone from clear water areas upstream.

Blue-green algae that may cover marginal rocks in slippery layers and give off foul odors upon seasonal decay masquerade under the names: Phormidium, Lyngbya, and Oscillatoria. Green algae that accomodate themselves to the putrid zone of active decomposition frequently include Spirogyra and Stigeoclonium. Gomphonema and Nitzschia are among the diatoms that are present here.

Algae begin to increase in numbers at about mile 36. Plankton, or free-floating forms, steadily become more abundant and reach their greatest numbers in algal blooms some 40 to 60 miles farther downstream. This is where reduced turbidity, a lack of settleable sewage solids, final mineralization of proteinaceous organics to nitrate-nitrogen fertilizers, and favorable oxygen relations result in an ideal environment for growth of abundant aquatic plants.

Algae that may be found abundantly here may be represented by the bluegreen genera Microcystis and Anabaena; the pigmented flagellates are represented by Euglena and Pandorina; the green algae by Cladophora, Ankistrodesmus, and Rhizoclonium; and diatoms by Meridion and Cyclotella. Rooted, flowering, aquatic plants that form underwater jungles here are represented by the "water pest." Elodea, and various species of pond weeds known as Potomogeton. Such aquatic forests and meadows present an excellent natural food supply for the aquatic animals, and also serve them with shelter. Thus, commonly as plants respond downstream in developing a diversified population in the recovery and clean water zones, animals follow a parallel development with a great variety of species. In such reaches where the stream consists of numerous alternating riffles and pools, a great variety of fish are likely to occur.

In the reach where algae are scare (sic: scarce), from about 0 to mile 36, various moulds and bacteria are the dominant aquatic plants. Sphaerotilus filaments may abound in riffle areas at about mile 36 where physical attachment surfaces are available and where oxygen, although low, is adequate. Bacterial slimes may cover rocks and other submerged objects and bank margins. Such slimes have an abundant supply of available food in readily usable form of carbohydrates, proteins and fats and their digestion products. They are not bothered especially by high turbidities or by settleable solids. They do well living in the center of sludge or near it, in what to them is an "apple-pie" environment.

BACTERIA AND THE CILIATES

Associated with the bacterial slimes are certain ciliated protozoans that feed on bacteria and engulf small particles of settleable organic matter. Such ciliates are also found in aeration tanks of sewage treatment installations as a component of activated sludge and on the surface of rock in trickling filter beds. Common ones are Epistilis, Vorticella, Colpidium, and Stentor.

Figure 6 illustrates the interrelations between bacteria and animal plankton, such as ciliated protozoans, rotifers and crustaceans. The quantities shown and the die-off curves for sewage bacteria in toto and for coliform bacteria separately are theoretically accurate. The center curve for ciliated protozoans and the last curve representing rotifers and crustaceans are more accurate in principle than in actual quantities.

After entering the stream as a part of the sewage, bacteria, including coliforms, reproduce to become abundant in an ideal environment. Here they feed on the rich organic matter of sewage and by multiplying rapidly offer a ready food supply for ciliated protozoans which are initially few in number. After about a day of flow the bacteria may be reduced through natural die-off and from the predatory feeding by protozoans. After about two days of flow, the stream environment becomes more ideal for the ciliates, and they form the dominant group of animal plankton. After seven days, the ciliates fall victim to rotifers and crustaceans which represent the principal microscopic animal life in the stream.

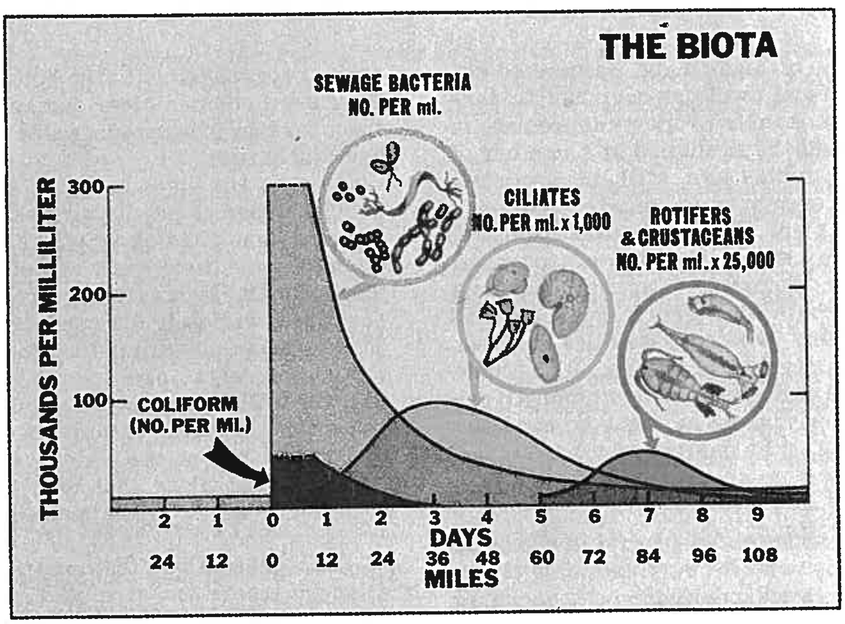

Figure 6 - Bacteria thrive and finally become prey of the ciliates, which in turn are food for the rotifers and crustaceans.

It has been long suspected that the efficiency of this sewage consuming biological machine depends upon a close-knit savage society in which one kind of organism captures and eats another. Classical research of some time past showed that a single kind of bacterium mixed with sewage in a bottle could not do an efficient or rapid job of breaking down the sewage. Several kinds could do a better job, supposedly because one bacterial type, in acting upon parts of the sewage as food, prepared it for acceptance by another. With several bacteria a multilateral attack was made possible. But even a system like this is inefficient. Bacteria work best only when they are growing rapidly and they do this when they multiply frequently by splitting into two. It is important then that they not be permitted to attain a stable high and lazy population. In the bottle the task of stabilizing sewage goes most rapidly when ferocious bacteria-eating ciliates are introduced to keep the population at a low and rapidly growing state.

These relations between the bacteria eaters and their prey, discovered in the bottle, apply as well to efficient functioning of a modern sewage treatment plant. In some sewage treatment plants, examination is made routinely to see how the battle lines are drawn up between the bacteria eaters and their prey. It now becomes more obvious why sewage disappears so efficiently from the stream. It also is clear why the bacteria, the ciliates, the rotifers and the crustaceans increase, persist for awhile, and then decrease along the course of passage of the stream.

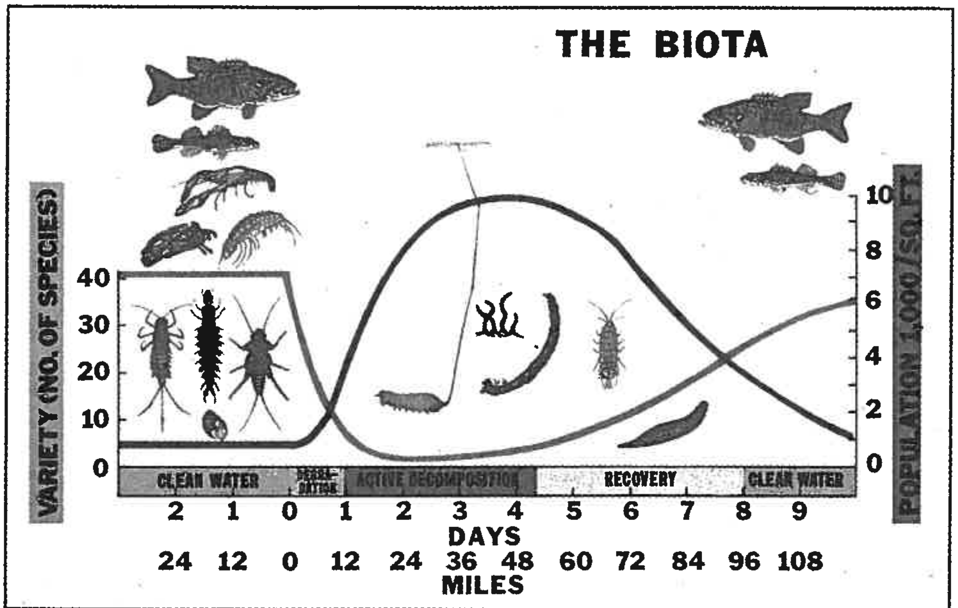

Figure 7 - The [upper] curve shows the fluctuations in numbers of species: the [lower] the variations in numbers of each.

THE HIGHER FORMS

Figure 7 illustrates the types of organisms and the numbers of each type likely to occur along the course of the stream under the assumed physical conditions that were stated earlier. The upper curve represents the numbers of kinds or species of organisms that are found under varying degrees of pollution. The lower curve represents the numbers of individuals of each species. In clean water above the city a great variety of organisms is found with very few of each kind represented. At the point of waste entry the number of different species is greatly reduced, and they are replaced by a different association of aquatic life. This new association demonstrates a severe change in environment that is drastically illustrated by a change in the species make-up of the biota. However, this changed biota, represented by a few species, is accompanied by a tremendous increase in the numbers of individuals of each kind as compared with the density of population upstream.

In clean water upstream there is an association of sports fish, various minnows, caddis worms, mayflies, stoneflies, hellgrammites, and gill-breathing snails, each kind represented by a few individuals. In badly polluted zones the upstream association disappears completely or is reduced, and is replaced by a dominant animal association of rattailed maggots, sludge worms, bloodworms and a few others, represented by great numbers of individuals. When downstream conditions again resemble those of the upstream clean water zone, the clean water animal association tends to reappear and the pollution tolerant group of animals becomes suppressed. Thus, clean water associations of animals may form parameters around polluted water reaches. Such associations may be indicative that water is fit for multiple uses, while the presence of a pollution tolerant association of animals indicates that water has restricted uses.

Pollution tolerant animals are especially well adapted to life in thick sludge deposits and to conditions of low dissolved oxygen. The rattailed maggot, Eristalis tenax, is not dependent on oxygen in water. This animal shoves its "snorkle-like" telescopic air tube through the water surface film to breathe atmospheric oxygen. Thus, even in the absence of oxygen it is one of the few survivors where most animals have suffocated. Those who have worked around sewage treatment installations have probably observed the flesh or milkish colored rattailed maggot in the supernatant over sludge beds where dewatering performance was poor. Commonly associated with it in this supernatant over sludge beds are the immature stages of the well-known "sewagefly," Psychoda, and wrigglers of the sewage mosquito, Culex pipiens. The rattailed maggot turns into a black and brownish banded fly about three-quarters of an inch long, called a "bee fly" because it closely resembles a bee. It differs by having two wings instead of four and does not sting. Sludge worms, Tubifex, are dependent upon the dissolved oxygen in water; however, they are well adjusted to oxygen famine and commonly are found in water with as little as half a part per million. They are actually aquatic earthworms, cousins of the terrestrial earthworms found in lawns and used as fish bait. These worms feed on sludge by taking it into the digestive tract. In passing it through their alimentary canal, they remove organic matter from it, thus reducing the biochemical oxygen demand. Sludge worms one and one-half inches long and as thick as a needle have been observed to pass fecal pellets totaling five feet nine inches through the digestive tract in 24 hours. Fecal pellets that are extruded from the anal openings have on occasion been found to have a biochemical oxygen demand of one-half of that of sludge that was not "worked-over" by them. The sludge worms are then, "actually crawling BOD," in that they incorporate sugars, proteins and fats that are present in sludge into their body cellular components. It may be difficult to visualize the magnitude of BOD removal that one worm, needle-thick in size and one and one-half inches long, can accomplish in relation to an extensive sludge deposit. However, when it is realized that from 7,000 to 14,000 of these worms may be found per square foot of bottom surface in sludges, considerable work is done in removing BOD. By the same token, for example, wrigglers of sewage mosquitoes. (Sic. ,) Culex pipiens, that feed on the organics of sewage and emerge as adults to fly out of water represent BOD removed. In this instance it is "flying COD" that is factually taken out of water, whereas the crawling BOD of sludge worms is not removed, but is recycled back as the worms die.

The worm-like body of organisms composing the pollution tolerant association of the rattailed maggot, sludge worms, blood worms, and leeches is an ideal type to have for successful living in sludge. As settleable solids fall to the bottom, such organisms are not trapped and buried in them to die, but by wriggling with their worm-like cylindrical bodies, manage to maintain their position near the surface of sludge in communication with the water interface. Sow-bugs that are shown in Figure 7 with the "wormy-horde" do have well-developed appendages, but their life may be marginal on stream bank areas and on the surface of rocks protruding from sludge covered bottoms. Thus, they are not buried by settleable solids.

The invertebrates shown in clean water do not form successful populations in streams where settleable solids sink to form sludge deposits. Because their appendages may become clogged with sludge as solids settle, they may be carried readily to the bottom and be buried alive.

POPULATION FLUCTUATION

Figure 8 shows that the population curve of Figure 7 is actually composed of a series of population maxima for individual species. The species form a significant pattern in reference to each other and to the varying strength of the pollutant as it decreases progressively downstream. Sludge worms such as Tubifex and Limnodrilus can better withstand pollution than other bottom invertebrates. Thus, they reach great numbers closer to the source than other bottom dwelling animals. In turn they are replaced in dominance by red midges, also called bloodworms or Chironomids, and then by aquatic sow-bugs, Asellus. The sludge worms and red midges are so numerous in contrast to the other organisms shown in Figure 8 that

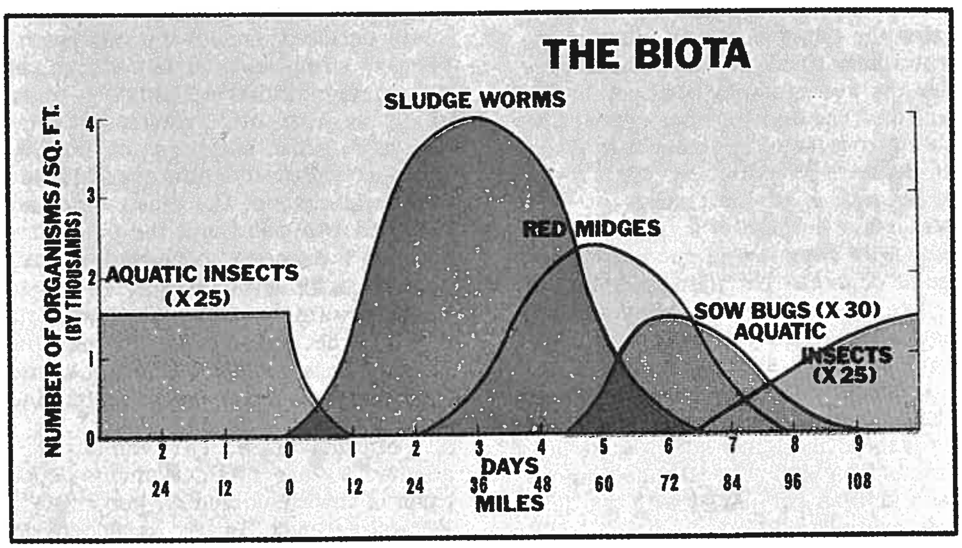

Figure 8 - The population curve of Figure 7 is composed of a series of maxima for individual species, each multiplying and dying off as stream conditions vary.

numbers of the latter are exaggerated 25 to 30 times to permit showing them effectively. Finally, when the effects of pollution have largely subsided in the environment, a variety of insect species represented by few individuals of each dominates the bottom habitat.

The story of pollution told here emphasizes that stream pollution and recovery may follow an orderly scheme under the influence of interacting physical, chemical and biological forces. Using streams as dumping places for sewage triggers the environmental and biotic changes that have been shown. These changes are not desirable. In most cases, in addition, they are hazardous to public health and otherwise impair the usefulness of valuable water resources. The needed remedy is to confine all of these interacting forces in an acceptable sewage treatment works so that this example of the Nation's water resources is protected for present and future use.

BIBLIOGRAPHY

1. Bartsch, A. F. 1948. "Biological Aspects of Stream Pollution." Sewage Works Journal, vol. 20, No. 2, pp. 292-302.
2. Brinley, Floyd J. 1942. "Biological Studies, Ohio River Pollution, I. Biological Zones in a Polluted Stream." Sewage Works Journal, vol. 14, No. 1, pp. 147-152.
3. Brinley, Floyd J. 1943. "Sewage, Algae and Fish." Sewage Works Journal, vol. 15, No. 1, pp. 78-83.
4. Claassen, P. W. 1932. "The Biology of Stream Pollution." Sewage Works Journal, vol. 4, No. 1, pp. 165-172.
5. Eliassen, R. 1952. "Stream Pollution." Scientific American, vol. 18, No. 3, pp. 17-21.
6. Hubbs, C. L. 1933. "Sewage Treatment and Fish Life." Sewage Works Journal, vol. 5, No. 6, pp. 1033-1040.
7. Ingram, W. M. 1957. Handbook of Biological References on Water Pollution Control, Sewage Treatment, Water Treatment. Public Health Service Publication No. 214 (Revised 1957), pp. 1-95.
8. Katz, M. and A. R. Gaufin. 1953. "The Effects of Sewage Pollution on the Fish Population of a Midwestern Stream." Transactions American Fisheries Society, vol. 82, pp. 156-165.
9. Lackey, J. B. and C. N. Sawyer. 1945. "Plankton Productivity of Certain Southeastern Wisconsin Lakes as Related to Fertilization. I. Surveys." Sewage Works Journal, vol. 17, No. 3, pp. 573-585.
10. Lackey, J. B. 1945. "Plankton Productivity of Certain Southeastern Wisconson Lakes as Related to Fertilization. II. Productivity." Sewage Works Journal, vol. 17, No. 4, pp. 795-802.
11. Olson, T. A. 1932. "Some Observations on the Interrelationships of Sunlight, Aquatic Plant Life and Fishes." Read at Sixty-second Annual Meeting, American Fisheries Society, Baltimore, Maryland, pp. 1-11.
12. Purdy, W. C. 1926. "The Biology of Polluted Water." Jour. Amer. Water Works Assoc., vol. 16, No. 1, pp. 45-54.
13. Richardson, R. E. 1928. "The Bottom Fauna of the Middle Illinois River, 1913-1925." Bull., Illinois Natural History Survey, vol. 17, No. 2, pp. 387-475.
14. Streeter, H. W. and E. B. Phelps. 1925. "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Service Bulletin No. 146, pp. 1-75.
15. Suter, R., and E. Moore. 1922. "Stream Pollution Studies." State of New York Conservation Commission, Albany N. Y., pp. 3-27.
16. Tarzwell, C. M. and A. R. Gaufin. 1953. "Some Important Biological Effects of Pollution Often Disregarded in Stream Surveys." Purdue University Engineering Bulletin, Proc. 8th Industrial Waste Conference (May 4-6, 1953), pp. 295-316.